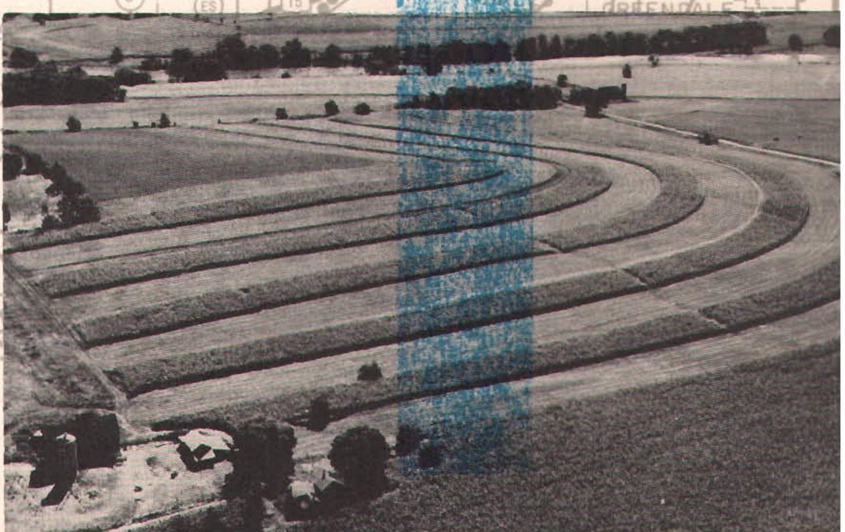
TECHNICAL REPORT NUMBER 18

STATE OF THE ART OF WATER POLLUTION CONTROL IN SOUTHEASTERN WISCONSIN



volume four

RURAL STORM WATER RUNOFF

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

COMMISSION MEMBERS

KENOSHA COUNTY
Donald L. Klapper
Donald E. Mayew
Francis J. Pitts,
Vice-Chairman

MILWAUKEE COUNTY
Richard W. Cutler,
Secretary
Evelyn L. Petshek
Harout O. Sanasarian

OZAUKEE COUNTY
Thomas H. Buestrin
John P. Dries
James F. Egan

RACINE COUNTY
George C. Berteau,
Chairman
John Margis, Jr.
Leonard C. Rauen

WALWORTH COUNTY
Anthony F. Balestrieri
Eugene A. Hollister
Harold H. Kolb

WASHINGTON COUNTY
Lawrence W. Hillman
Paul F. Quick
Joseph A. Schmitz,
Treasurer

WAUKESHA COUNTY
Charles J. Davis
Robert F. Hamilton
Lyle L. Link

COMMISSION STAFF

Kurt W. Bauer, P.E. .... Executive Director
Harlan E. Clinkenbeard .... Assistant Director
Keith W. Graham, P.E. .... Assistant Director
John A. Boylan .... Administrative Officer
John W. Ernst .... Data Processing Manager
Philip C. Evenson .... Chief Community Assistance Planner
Mark P. Green, P.E. .... Chief Transportation Planner
Leland H. Kreblin .... Chief Planning Illustrator
William D. McElwee, P.E. .... Chief Environmental Planner
Thomas D. Patterson .... Chief of Planning Research
Bruce P. Rubin .... Chief Land Use Planner

STANLEY CONSULTANTS, INC.

Donald A. Haselhoff .... Project Engineer
Donald G. Pauken .... Environmental Analyst
Douglas A. Wallace .... Department Head, Water Resources Planning

Special acknowledgement is due Lyman F. Wible, P.E., SEWRPC Water Quality Program Coordinator, and Robert P. Biebel, P.E., SEWRPC Sanitary Engineer, for their contributions to this report.

TECHNICAL ADVISORY COMMITTEE ON AREAWIDE WASTEWATER TREATMENT AND WATER QUALITY MANAGEMENT PLANNING

Robert J. Borchardt, Chairman .... Chief Engineer and General Manager, Milwaukee-Metropolitan Sewerage Commissions
Raymond J. Kipp, Vice-Chairman .... Dean, College of Engineering, Marquette University
William D. McElwee, Secretary .... Chief Environmental Planner, SEWRPC
Vinton W. Bacon .... Professor, College of Applied Science and Engineering, University of Wisconsin-Milwaukee
Robert E. Badger .... Vice-President, Corporate Planning, Snap-On Tools Corporation, Kenosha; Wisconsin Manufacturers' Association
Anthony S. Bareta .... Director, Milwaukee County Planning Commission
Kurt W. Bauer .... Executive Director, SEWRPC
Frank R. Boucher .... Director, Environmental Department, Wisconsin Electric Power Company
Frederick H. Chlupp .... Land Use and Park Administrator, Washington County
Arnold L. Clement .... Planning Director and Zoning Administrator, Racine County
Norbert H. Dettmann .... Washington County Board Supervisor
Alvin A. Erdman .... District Conservationist, U. S. Soil Conservation Service, Milwaukee and Waukesha Counties
Kent B. Fuller .... Chief, Planning Branch, Region V, U. S. Environmental Protection Agency
Herbert A. Goetsch .... Commissioner of Public Works, City of Milwaukee
Thomas N. Hentges .... Former Racine County Board Supervisor; Former Chairman, Town of Burlington
Lester O. Hoganson .... City Engineer, City of Racine
Helen M. Jacobs .... League of Women Voters
Myron E. Johansen .... Former District Conservationist, U. S. Soil Conservation Service, Ozaukee and Washington Counties
James A. Johnson .... Walworth County Planner
Leonard C. Johnson .... Southeast Area Representative, Wisconsin Board of Soil and Water Conservation Districts
Melvin J. Johnson .... Chairman, Town of Norway; Racine County Board Supervisor
Thomas A. Kroehn .... Administrator, Division of Environmental Standards, Wisconsin Department of Natural Resources
Elwin G. Leet .... Racine County Agri-Business Agent
William G. Murphy .... Professor, Marquette University; Engineers and Scientists of Milwaukee
O. Fred Nelson .... Manager, Kenosha Water Utility
Wayne A. Persig .... District Director, Farmers Home Administration, U. S. Department of Agriculture
Herbert E. Ripley .... Health Officer, Waukesha County Department of Health
Donald A. Roensch .... Director of Public Works, City of Mequon
Harold F. Ryan .... Washington County Board Supervisor
Walter J. Tarmann .... Executive Director, Park and Planning Commission, Waukesha County
Mitchell P. Urbanski .... Engineer, American Motors Corporation; Member, Kenosha County Air and Water Pollution Committee
Rodney M. Vanden Noven .... Director of Public Works, City of Waukesha
Frank A. Wellstein .... City Engineer, City of Oak Creek

Cover Photo Courtesy of U. S. Soil Conservation Service

TECHNICAL REPORT
NUMBER 18

STATE OF THE ART OF WATER POLLUTION CONTROL IN SOUTHEASTERN WISCONSIN

Volume Four

RURAL STORM WATER RUNOFF

Prepared by Stanley Consultants, Inc., for the
Southeastern Wisconsin Regional Planning Commission
P. O. Box 769
Old Courthouse
916 N. East Avenue
Waukesha, Wisconsin 53186

The preparation of this report was financed through a planning grant from the U. S. Environmental Protection Agency in cooperation with the Wisconsin Department of Natural Resources under the provisions of Section 208 of the Federal Water Pollution Control Act.

December 1976

Inside Region $2.50
Outside Region $5.00

(This page intentionally left blank)

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

916 NO. EAST AVENUE • P.O. BOX 769 • WAUKESHA, WISCONSIN 53186 • TELEPHONE (414) 547-6721

Serving the Counties of: KENOSHA
MILWAUKEE
OZAUKEE
RACINE
WALWORTH
WASHINGTON
WAUKESHA

December 21, 1976

STATEMENT OF THE EXECUTIVE DIRECTOR

Pursuant to the provisions of Section 208 of the Federal Water Pollution Control Act, the Southeastern Wisconsin Regional Planning Commission on July 1, 1975, undertook an areawide water quality management planning program. The objectives of this program are: to determine current stream and lake water quality conditions within the Region; to compare these conditions against established water use objectives and supporting water quality standards; to explore alternative means of meeting those objectives and standards through the abatement, as necessary, of both point and diffuse sources of water pollution; and to recommend the most cost-effective means of meeting the established objectives and standards over time. The formulation of sound recommendations for the abatement of water pollution and attainment of water use objectives requires among other things, definitive knowledge of the state of the art of the technology of wastewater treatment and disposal. If the areawide water quality management plan is to be sound and practical, it must seek to properly apply, as necessary, the best available wastewater treatment technology and avoid the proposed application of outmoded as well as of unsound, unreliable, or unsafe practices.

In order to assure that the areawide water quality management plan would be founded on a sound technical basis, the Commission retained a consulting engineering firm—Stanley Consultants, Inc.—to conduct a review of the state of the art of water quality management. The study was intended to provide definitive data on the applicability, effectiveness, reliability, and cost of the various techniques currently available for the treatment of sanitary and industrial waste waters, urban storm water runoff, rural storm water runoff, and the residual solids—or sludges—resulting from the treatment of these waste waters. The findings of this review of the state of the art are presented in a four volume report. This, the fourth volume, presents the state of the art of the *control of pollution* from agricultural runoff. The information contained in the report, like that contained in the third volume, which deals with the control of pollution from urban runoff, is required in the areawide water quality management planning effort to deal with diffuse, as opposed to point sources of water pollution. Because there has been considerably less experience to date with the abatement of water pollution from diffuse sources than from point sources, the state of the art for the former is less well developed than for the latter. This difference in the state of the art is especially pronounced in the ability to assess the effectiveness of control techniques. Methods proposed for the control of pollution from diffuse agricultural pollution sources generally represent adaptations of methods intended to abate soil erosion by known amounts, but knowledge of the attendant achieved reductions in nutrient, pesticide, or toxic components is limited. This report attempts to present in a concise manner the cost and effectiveness of the various techniques that are available to control water pollution associated with agricultural runoff, techniques developed primarily by agricultural engineers and soil and water conservationists.

It is the hope of the Commission staff that, in addition to properly reflecting the current state of the art of waste water management, this volume and its three companion volumes will actually contribute to that state of the art by providing a concise presentation of the techniques involved; evaluating their application to water quality management within southeastern Wisconsin; and presenting the technical information in a format which permits consideration of the cost of alternative means of meeting the water use objectives applicable to the lakes and streams of the Region.

Respectfully submitted,

Kurt W. Bauer
Executive Director

(This page intentionally left blank)

STANLEY CONSULTANTS, INC

STANLEY BUILDING
MUSCATINE, IOWA 52761
TELEPHONE : 319/264-6600
CABLE : STANLEY MUSCATINE IOWA
TELEX : 468402

October 29, 1976

Southeastern Wisconsin Regional
Planning Commission
916 N. East Avenue
Old Court House
Waukesha, Wisconsin 53186

Attention Mr. Kurt W. Bauer, Executive Director

Gentlemen:

Re: State-of-the-Art Studies
208 Water Quality
Management Planning Program

We are pleased to submit this final report entitled "Agricultural Runoff Control Alternatives and Cost Information." This final report reflects modifications and additions to our August 27, 1976 preliminary draft report as a result of your constructive comments relative to that document.

We have appreciated the opportunity to prepare this element of your 208 Water Quality Management Planning Program and trust you will find the information provided useful in your continuing planning efforts. Should you have any questions relative to this report, please feel free to call us.

Sincerely,

STANLEY CONSULTANTS, INC.

R. G. Fritchie, P.E.
Project Manager

(This page intentionally left blank)

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS

Chapter I

INTRODUCTION

GENERAL

This report presents alternatives for controlling surface and ground water pollution from agriculturally-related activities. The emphasis is on activities involving agriculture and woodland land uses which together comprised about 68 percent of the Region's total land use and about 84 percent of the Region's nonurban land use in 1970.[1] Agricultural land use occupied 1,040,121 acres while woodlands covered 125,286 acres. Information is provided on the potential pollutant loading that may be induced on regional waters from these activities. Information is supplied, also, on descriptions, costs, and effectiveness of options available to reduce these potential loadings. Information, moreover, is presented in sufficient detail to be useful for subsequent development and evaluation of regional alternatives for control of agricultural nonpoint water pollution sources.

SCOPE

The specific scope of this investigation covers:

1. An evaluation of source control methods (farming practices and soil conservation activities) for agricultural nonpoint water pollution sources.

2. A description of the general effectiveness, applicability to the Region, and potential costs of the methods evaluated.

3. A description of examples of effective soil conservation techniques being utilized throughout the Region and their general acceptability and utilization, based on information available from the U. S. Soil Conservation Service and other agencies.

Agricultural nonpoint water pollution sources considered include soil erosion, pesticide and fertilizer application, and feedlots. Specifically excluded from this investigation are the use of agricultural lands as the ultimate depository for wastewaters or sludges from water or wastewater treatment facilities and control of urban runoff from residential subdivisions in rural areas. These topics are adequately covered in other state of the art studies for the Region.

STUDY AREA

Controls described in this report have potential application in the Southeastern Wisconsin Region consisting of Kenosha, Milwaukee, Ozaukee, Racine, Walworth, Washington, and Waukesha Counties (see Map 1).

Appendices

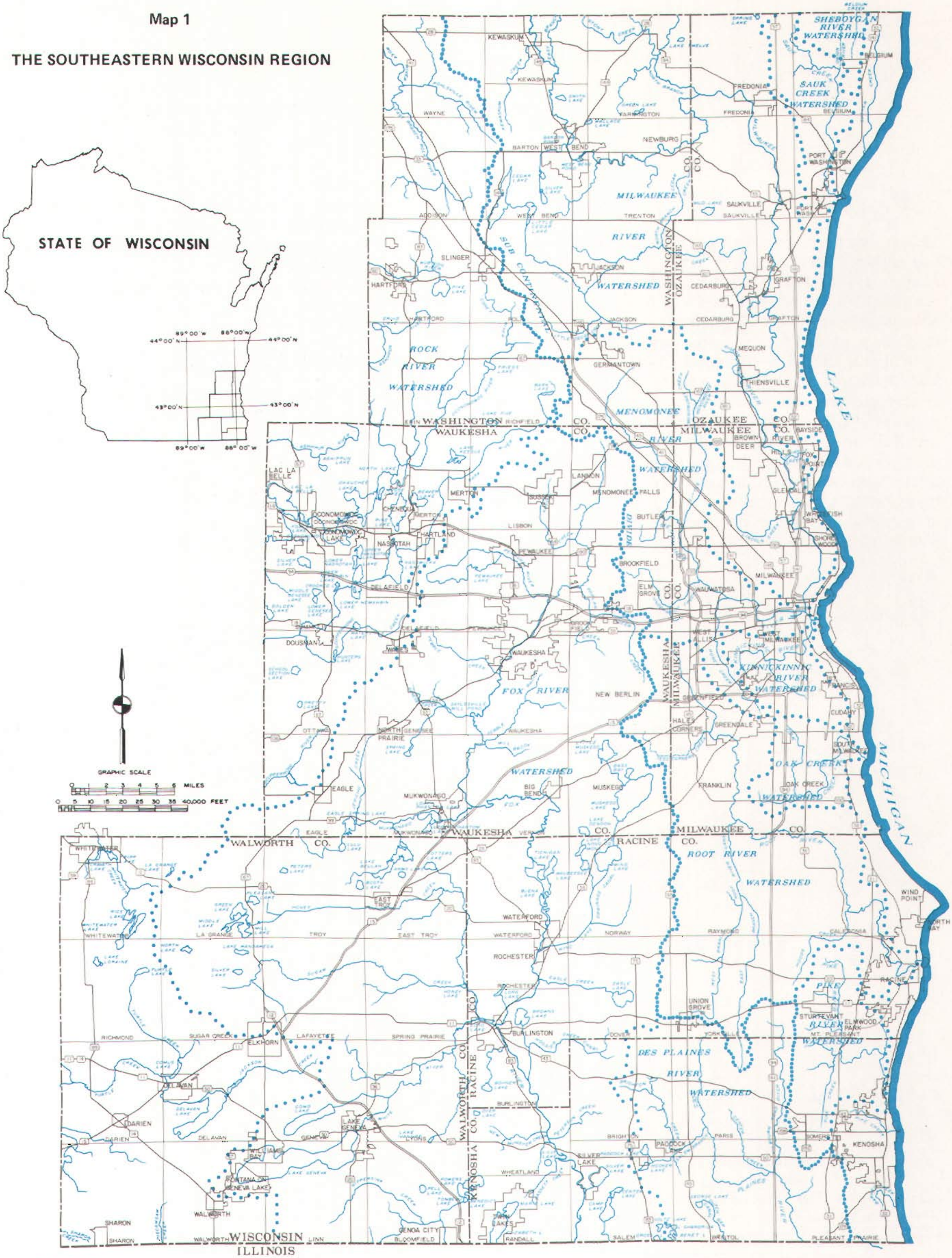
Included as appendices in this report are Appendix A containing full references used and Appendix B, a list of abbreviations used throughout the text and in the tables.

---

[1] *Southeastern Wisconsin Regional Planning Commission, A Regional Land Use Plan and a Regional Transportation Plan for Southeastern Wisconsin—2000, Planning Report No. 25, Volume 1, April 1975.*

Map 1

THE SOUTHEASTERN WISCONSIN REGION



Source: SEWRPC.

Chapter II

SOURCES AND MOVEMENT OF POTENTIAL POLLUTANTS

INTRODUCTION

A pollutant is a material introduced into a system thereby making that system unfit for a specific purpose. The primary emphasis in this report is on materials that reach surface or ground waters from agricultural activities and on methods to control movement of these materials from agricultural lands to the receiving waters. Subsequent Section 208 water quality management planning reports for the Region will describe the quantity of materials reaching receiving waters in the Region, whether or not the materials are pollutants, and whether or not alternative controls described in remaining chapters of this report should be applied. The major potential pollutants from agricultural activities are sediment, nitrogen, phosphorus, pesticides, and organic materials.

LOADINGS FROM THE AIR

Many factors such as wind erosion, biological respiration, volcanic action, and fossil fuel combustion cause materials to enter the earth's atmosphere. The atmosphere has two natural air cleansing mechanisms: gravity and precipitation. These mechanisms act upon airborne constituents to cause the movement of these materials back to the earth surface. Dry fallout due to gravity and precipitation washout and rainout are significant sources of potential pollutant loading and cannot be overlooked in assessing the quality of area waters.

Several investigators have studied the contribution of materials to the land or water surface from these sources. Results pertinent to the study area are summarized in Table 1. Additional comments that may be important in data analysis are these:

1. Wisconsin SO_2 concentrations are low in summer and high in winter. This may result from increased fossil fuel usage for space heating.[1]

2. Ammonia and organic nitrogen in Wisconsin are highest in the spring (40 percent of annual load occurs in April, May, and June) and lowest in the winter (3 to 5 percent of annual load occurs from October to April). Nitrate nitrogen is relatively constant.[2] This may reflect natural biological nitrification and denitrification as well as aerosols from fertilizer application.

3. For Madison, Wisconsin, the highest phosphorus load is in the summer because of sources associated with pollen, bird droppings, and seeds in the air.[3] The major source of other constituents was fugitive dust. An allowable load of 0.62 pound per acre per year total phosphorus without eutrophication of area lakes was cited. An allowable load of 8.9 pounds per acre per year total nitrogen also was presented.

4. Recent data indicate that atmospheric phosphorus loadings may be largely associated with precipitation events and not dry dustfall. Dustfall is mainly composed of particulates greater than 30 microns in size. Phosphorus is usually attached to particulate matter less than 30 microns in size which can only be effectively removed by precipitation scavenging.[4]

It can reasonably be assumed that a major source of most potential atmospheric pollutant constituents is fugitive dust. Wind erosion, vehicular traffic, and air pollution point sources contribute to the atmospheric dust.

Several methods have been employed to reduce dust emissions from these sources. Expected control efficiencies are shown in Table 2. The efficiency of controls relates to the amount of dust generated with the indicated controls versus that generated without controls. The potential pollution load due to dry fallout is difficult to quantify. Total dustfall may vary from 5 to 60 tons per square mile per month depending on the distance from an urban area, the season of the year, and the occurrence of precipitation events.

The quality of rainwater runoff and snowmelt reaching area surface and ground waters can be expected to approximate loadings and concentrations given in Table 1 if no additional pick-up or deposition occur as the precipitation waters move over or through the land surface.

---

[1] *R. G. Hoeft; D. R. Keeney; and L. M. Walski, "Nitrogen and Sulfur in Precipitation and Sulfur Dioxide in the Atmosphere in Wisconsin," Journal of Environmental Quality, Volume 1, No. 2, 1972.*

[2] *Ibid.*

[3] *J. D. Chapin and P. E. Uttormark, "Atmospheric Contributions of Nitrogen and Phosphorus," University of Wisconsin Water Resources Center, Madison, Wisconsin, February 1973.*

[4] *T. J. Murphy and P. V. Doskey, "Inputs of Phosphorus from Precipitation to Lake Michigan," prepared for U. S. Environmental Protection Agency, EPA 600/3-75-005, December 1975.*

Table 1

LOADINGS FROM ATMOSPHERE TO LAND RESULTING FROM DUSTFALL, RAIN, AND SNOW

Location	Loadings (Pounds/acre/year)							Notes	Reference Document
	BOD_5	TSS	TN	NH_3-N	NO_3	TP	OP		
Lake Wingra	--	--	13.6	3.6	3.0	0.70	0.13	Dry fallout	J. W. Kluesner, "Nutrient Transport and Transformations in Lake Wingra, Wisconsin," Ph.D. thesis, Water Chemistry Department, University of Wisconsin-Madison, 1972.
Lake Wingra	--	--	7.0	2.5	2.8	0.20	0.16	Precipitation washout (35.5 inches rain)	Ibid.
Rural Wisconsin	--	--	11.7	2.6	2.4	--	--	Precipitation (S = 14.7 pound/acre/year)	R. G. Hoeft; D. R. Keeney; and L. M. Walski, "Nitrogen and Sulfur in Precipitation and Sulfur Dioxide in the Atmosphere in Wisconsin," Journal of Environmental Quality, Volume 1, No. 2, 1972.
Rural Wisconsin	--	--	26.9	10.9	3.1	--	--	Precipitation near barnyard	Ibid.
Wisconsin	--	--	8.9	--	--	0.09-0.9[a]	--	Rainfall, snowfall, and dry fallout	J. D. Chapin and P. E. Uttormark, "Atmospheric Contributions of Nitrogen and Phosphorus," University of Wisconsin Water Resources Center, Madison, Wisconsin, February 1973.

Location	Concentrations (mg/1)							Notes	Reference Document
	BOD_5	TSS	TN	NH_3-N	NO_3	TP	OP		
East Shore Lake Michigan . . .	--	--	--	--	--	0.032	0.014	Rain[b]	J.T. Murphy and P.V. Doskey, "Inputs of Phosphorus from Precipitation to Lake Michigan," prepared for U.S. Environmental Protection Agency, EPA 600/3-75-005, December 1975.
East Shore Lake Michigan . . .	--	--	--	--	--	0.038	0.023	Snow	Ibid.
East Shore Lake Michigan . . .	--	--	--	--	--	0.0024	0.0015	Snow from year 1650	Ibid.
Rural Wisconsin	--	--	2-12	0-3	0.1-0.5	--	--	Precipitation	Hoeft, Keeney, Walski, "Nitrogen and Sulfur in Precipitation and Sulfur Dioxide in the Atmosphere in Wisconsin."
Rural Wisconsin	--	--	2-31	0-13	0-1.7	--	--	Precipitation near barnyard	Ibid.
Rural Ohio	3	4	--	0.43	0.37	0.035	0.02	Rain-weighted mean	Nonpoint and Intermittent Point Source Controls - Development of Structural Control Techniques and Cost Information, prepared by Stanley Consultants for the Miami Conservancy District, January 1976.
Rural Ohio	1-9	1-18	--	0.13-1.3	0-0.8	0-0.011	0-0.05	Rain-range of values 11 storms	Ibid.
Atlanta	4	10	0.21	0.13	--	0.03	--	Rain-weighted mean	Nonpoint Pollution Evaluation - Atlanta Urban Area, prepared by Black Crow and Ediness for Savannah District Corps of Engineers, 1975.

[a] *Dry fallout load equals three times precipitation load for TP (two for TN) and snow contributes 25 to 50 percent of annual precipitation load.*

[b] *The total phosphorus concentration was 25 ug/1 in the rain when the air contained 0.055 ug/m^3 and was 56 ug/1 in rain when air contained 0.110 ug/m^3. The concentration decreased as the amount of rain increased as shown below:*

Total Rainfall (cm)	*<0.5*	*0.5 to 1*	*1 to 1.5*	*1.5 to 2*	*2 to 3*	*>3*
Medium TP Concentration (mg/1)	*0.075*	*0.040*	*0.025*	*0.020*	*0.015*	*0.010*

Source: Stanley Consultants.

Decreased loadings can be expected as a direct function of the cleanliness of the air. Air pollution programs in urban areas can help prevent high atmospheric load potentials, but a significant load may still reach area waters due to precipitation events which will still remove naturally induced materials from the air.

The atmospheric loadings added directly by atmospheric sources to surface waters is a function of the surface area of those waters. The contribution to the larger lakes and especially Lake Michigan from this source can be significant.

AGRICULTURAL INPUTS

A brief discussion of possible agricultural pollutant inputs provides a general insight into why controls may be needed.

Table 2

DUST CONTROLS AND REMOVAL EFFICIENCIES

Construction Controls	Percent Controlled	Agricultural Controls	Percent Controlled	Road Dust Controls	Percent Controlled
Watering	40-50	Continuous cropping	20-25	Paving and right-of-way improvements	80-85
Chemical stabilization of completed cuts and fills	60-80	Limited irrigation of fallow fields	10-20	Surface treatment with penetration chemicals	40-50
Treatment of temporary access and haul road on or adjacent to site	40-50	Windbreaks Zero tillage	0- 5 40-50	Soil stabilization chemicals worked into the roadbed	40-50
Minimal exposure periods for active construction sites	40-50	Inter-row plantings of grain on widely spaced row crops	10-15		
Paving of haul roads	80-85	Stubble, crop residue, or mulch left on fields after harvest for wind protection Spray on chemical stabilization	5-10 35-40		

Source: Adapted from Guidelines for Air Quality Maintenance Planning and Analysis, Volume 3, Control Strategies, U. S. Environmental Protection Agency, July 1974.

Many materials added to the soil to enhance crop production may be washed into streams and lakes. Other waste products from agricultural activities may also be washed into streams or be leached to the ground water system. Some will be associated with sediment loss; others may be dissolved in runoff or percolating water. Sediment itself may be a major pollutant reducing the utility of surface water resources.

Fertilizers

The use of chemical fertilizers, along with other practices, has provided adequate crop production for domestic consumption as well as providing additional quantities for export. Increased fertilizer use in recent years to enhance crop production has prompted many questions concerning nutrient pollution of surface and ground waters. Nutrient elements, especially nitrogen and phosphorus, can be significant pollutants. Both can accelerate the eutrophication process in water; nitrogen, in the nitrate form, can be a direct threat to the health of infants at concentrations above about 20 mg/l. The composition of nitrogen and phosphorus substances in the soil/water system and the mechanisms by which they are lost from soils differ greatly. Because the forms of both substances are numerous and interdependent, determining the contribution of each form to surface water is difficult.

Organic or humus nitrogen lost from soils into surface water is generally associated with sediment. However, most of the nitrogen lost from soil is in the completely soluble inorganic nitrate form. In contrast, most of the phosphorus in soil, whether it comes from organic or inorganic sources, is contained within or attached to soil particles. Soluble phosphate content of surface runoff is usually very low, but concentrations may be significant in runoff from areas containing decaying vegetation. Phosphorus lost from agricultural lands is generally associated with sediment.

It has not been possible to adequately quantify the relative contribution of nitrogen and phosphorus due to fertilizer application versus that produced by natural mineralization of the organic matter in the soil to the total nutrient loss observed. Almost all fertilizer used in nonurban areas of the Region is applied to cropland with no known woodland fertilization programs in existence.

Other Chemicals

Contamination of the environment by pesticides is a subject of much recent concern. Pesticide data indicate that the major usage in the United States is limited to a relatively small number of chemical compounds. However, widespread and significant environmental pollution problems are associated with those pesticides. Degradation products of the chlorinated hydrocarbon pesticides are not only toxic, but they also persist long enough to allow their escape from control after application and/or to permit their uptake and concentration in living organisms. This phenomenon of biological magnification is especially significant with the fat soluble (chlorinated hydrocarbon) pesticides.

Pesticides may be dissolved or adsorbed and transported with sediment. When pesticides are transported in an aqueous phase, hydrological factors describing the movement of the water from the source to the point of discharge in surface water must be known to predict the probable extent or impact of the potential pollution. When pesticides are carried with sediment, the rates of transport of suspended sediment, as well as existing bedload, must be considered. As with fertilizer use, most pesticide use in the Region is for croplands.

Feedlots

Similarity exists between nutrients contained in cropland runoff and feedlot runoff. Primary constituents again are various organic and inorganic forms of nitrogen and phosphorus. The same detrimental effects (excessive algal blooms often resulting in decreased dissolved oxygen concentrations in the water body) associated with nutrient runoff from agricultural land are also caused by release of nutrient-rich wastes from feedlot operations.

Major objectionable constituents in feedlot runoff are suspended solids, nutrients, and organic material. Suspended solids discharged to streams consist largely of organic material (in contrast to the largely inorganic sediment from rural runoff), and often become aesthetically unacceptable from a sight and odor consideration as they undergo anaerobic decomposition. Additional oxygen requirements imposed upon the stream can be of sufficient magnitude to create a severe ecological imbalance in particular reaches of the stream causing shifts in the numbers and characteristics of aquatic species. Beneficial organisms may be eliminated from the stream and increased populations of unfavorable growths may result. Groundwaters near feedlots can be contaminated by leached nitrates.

MOVEMENT OF POTENTIAL POLLUTANTS

The preceding discussion has centered on materials added to the land surface by various activities. Man can control these activities to a certain extent to reduce the material available for movement. The materials become a water pollutant only if they reach the surface or ground waters of the Region in sufficient quantities to render these receiving waters unsuitable for a specific purpose.

Surface Water

There are many sources of potential pollutants onto the land surface, among them atmospheric sources; fertilizer; chemicals; and wastes from vegetation, animals, land development, and man. The amount of plant nutrients, pesticide, other chemicals, and sediment being washed into surface waters can significantly affect the aquatic habitat. The reduction of chemicals and sediment transported to the stream will eventually improve the area surface water quality. The amount of pollutant reaching the stream is directly related to the amount of pollutant on the land surface and the quantity of rainfall in the area. The previous discussions indicate that:

1. The primary moving agent is water from precipitation events. The water can lead to leaching to groundwaters or the transfer of dissolved or suspended materials from the air or land surface to surface waters.

2. Pesticides, phosphorus, heavy metals, and many other chemicals adhere to soil particles (particularly clay components of the soil) and generally only reach surface waters when attached to such particles; exceptions being soluble materials from decaying vegetation.

3. Resolving the sediment problem will minimize most potential agricultural pollutant problems concerning surface waters; exceptions being the organic, bacterial, and nitrogen loads which are not directly correlated with sediment.

Groundwaters

The soil and subsoil become the final depository for many wastes from man's activities. The soil and soil microbes are capable of accommodating many wastes (wastewater, sewage sludge, animal waste) and reducing or removing their pollution impact. Soil has a fixed capacity for accomplishing this reduction; overloading or bypassing the soil can lead to impairment of groundwater quality. The major potential pollutant is inorganic nitrate nitrogen which has been shown to move below the soil profile. Groundwaters feed many of the streams in the Region and thus can lead to high total nitrogen loads in streams, rivers, and lakes of the Region.

Sediment

Several potential sediment sources in the Region are agricultural land, highway and railroad backslopes, urban runoff, erosion from land development and construction sites, streambed scour and streambank erosion, woodlands, and surface mineral extraction areas.Because of the land areas involved, erosion from agricultural and woodlands are considered to be the most significant sources in the Region of sediment transported to surface waters. Additional stream sediment loads are due to streambank erosion and streambed scour.

The sediment problem begins with erosion. The degree of soil erosion depends on soil characteristics and topography, land cover conditions, and regional rainfall characteristics. The principal soil characteristic considered is erodibility or the relative susceptibility of the soil to erosion. Generally, fine-textured soils (high in silts and clays) are more erodible than coarse textured (sandy) soils. Steeper and longer slopes are usually more susceptible to erosion than gentler and shorter slopes. Land cover refers to the ability of the vegetation to absorb the impact energy of rainfall. Rainfall characteristics include amount, duration, and intensity. If factors other than rainfall are held constant, the erosion rate is directly proportional to the total kinetic energy of a storm.

Onsite soil loss from water erosion can be predicted using the Universal Soil Loss Equation: $A = RKLSCP$.

where: A = Annual soil loss in tons per acre
R = Rainfall factor
K = Soil erodibility factor

L = Length of slope
S = Percent of slope
C = Cropping system
P= Conservation practice

For water quality planning, however, prediction of suspended sediment levels entering surface water is more important than prediction of "onsite" erosion. Sediment yield is the amount of eroded soil material that is transported and deposited in a stream as suspended sediment, settled bed material, or both. Depending on available data, average annual sediment yields can be calculated using: 1) gross erosion and sediment delivery ratios, 2) measured sediment accumulations, and 3) sediment rating curves, flow duration techniques, and predictive equations.

The large number of variables used to calculate gross erosion and sediment production make development of any average numbers impractical. However, the U. S. Environmental Protection Agency (EPA)[5] has prepared representative erosion rates for various land uses (see Table 3), and others[6] have estimated sediment production rates (yields) for various size drainage areas in the U. S. (see Table 4).

Movement of the sediment to the stream from the land is a function of transport. Transport can occur by wind or water action. The more significant transport is by water action. Estimating the loads to the stream from agricultural lands is difficult. Determining the transport of sediment in the stream after it enters is even more difficult although several mathematical formulations have attempted to describe the phenomenon.[7]

Methods of transport directly or indirectly responsible for the movement of sediment from land areas to surface waters include runoff, wind, landslides, and mechanical agents. Quantification methods for pollution from land activities are available only for soil erosion and suspended sediment yield. Predictive models are not available for most other potential pollutants. An assumption of soil attachment must usually be made or the material must have an assumed solubility in runoff waters from land areas if instream loadings are to be predicted.

As eroded soil moves toward the waterway, transport of the smaller clay particles in runoff water predominates over the transport of larger particles which settle out and redeposit on land. A recent report[8] indicates typical pollutant contents of dry sediment found in streams in the Region as shown in Table 5.

As sediment is deposited back on the land following erosion, the potential for redissolving chemicals and nutrients attached to the sediment exists. This could lead to continued inputs of these materials to receiving waters even though soil erosion and sediment delivery is reduced.

The importance of sediment control must be measured by the effects of sediment or its attached constituents on the natural system. Prolonged periods of high sediment concentrations adversely affect stream biota. Benthic communities can be reduced or eliminated if sediment fills the interspaces of a gravel and rubble stream bottom. The planktonic community can also be destroyed by abrasive

Table 3

REPRESENTATIVE RATES OF EROSION FROM VARIOUS RURAL LAND USES

Land Use or Cover	Annual Rate (tons/square mile)	Erosion Rate Relative to Forest = 1
Forest	24	1
Grassland	240	10
Abandoned Surface Mines	2,400	100
Cropland	4,800	200
Harvested Forest	12,000	500
Active Surface Mines	48,000	2,000
Construction	48,000	2,000

Source: U.S. Environmental Protection Agency, Methods for Identifying and Evaluating the Nature and Extent of Non-Point Sources of Pollutants, EPA 430/9-014, U.S. Government Printing Office, October 1973.

Table 4

SEDIMENT PRODUCTION RATES FOR DRAINAGE AREAS IN THE UNITED STATES

Watershed Size (square mile)	Number of Measurements	Average Annual Rate (acre-ft/square mile)
10	650	3.80
10-100	205	1.60
100-1,000	123	1.01
1,000	118	0.05

Source: T.L. Willrich et al, "Agricultural Practices and Water Quality," in Proceeding of a Conference Concerning the Role of Agriculture in Clean Water, November 1969, Iowa State University, Ames, Iowa, November 1970.

[5] *U. S. Environmental Protection Agency, Methods for Identifying and Evaluating the Nature and Extent of Non-Point Sources of Pollutants, EPA 430/9-73-014, U. S. Government Printing Office, October 1973.*

[6] *T. L. Willrich et al, "Agricultural Practices and Water Quality" in Proceeding of a Conference Concerning the Role of Agriculture in Clean Water," November 1969, Iowa State University, Ames, Iowa, November 1970.*

[7] *Walter Hans Graf, Hydraulics of Sediment Transport, McGraw-Hill, New York, New York, 1971.*

[8] *A. D. McElroy et al, "Loading Functions for Assessment of Water Pollution from Nonpoint Sources," EPA/ 2-76-151, May 1961.*

Table 5

CONSTITUENTS OF TYPICAL STREAM SEDIMENTS IN SOUTHEASTERN WISCONSIN

Constituent	Quantities Found in Sediment[a]
Nitrogen (N)	0.16 to 0.6 grams/100 grams of sediment with from 5 to 15 percent available as ammonia and nitrate nitrogen. The remainder is organically bound in the soil.
Phosphorus (P)	0.07 to 0.3 grams/100 grams sediment with from 5 to 10 percent available as orthophosphate.
Organic Matter	1.6 to 15 grams/100 grams sediment.
Pesticides[b]	From 0.01 to 0.32 parts per million (ppm) of common pesticides (aldrin, chlordane, DDE, DDT, dieldrin, heptachlor, trifluralin) were found in soils.
Heavy Metals[c]	Range highly variable, average values are Cr = 36 ppm, Cu = 14 ppm, Fe = 15,000 ppm, Pb = 14 ppm, Ni = 13 ppm, Ti = 3,000 ppm, Zn = 36 ppm. Usually less than 1 percent is soluble.

[a]The concentration found in sediment is usually two to four times the concentration found in the soil due to on-land sediment deposits from erosion.

[b]Atrazine and Ramrod losses ranged from 0.16 to 1.8 percent of material applied.

[c]The concentration of arsenic in soils ranged from 0.34 to 10.0 ppm.

Source: A.D. McElroy et al, "Loading Functions for Assessment of Water Pollution from Nonpoint Sources," EPA/2-76-151, May 1976.

sediment action; by physical settling, covering, and smothering of attached algae; and by reducing illumination necessary for photosynthesis. The amount of food available for fish ultimately is reflected in the size of the fish population. Water containing high concentrations of suspended matter will produce limited plant life and consequently have a poor fishery. Silt produces the most harmful effects on fish reproduction, specifically spawning, and on fish egg and fish larvae survival.

Another effect on the fish population is changes in species composition. Silt blankets rocky areas eliminating cover for smaller fish and nesting areas for larger ones. Many fish species are sight feeders and due to the foraging difficulties avoid turbid water if possible. The result is that less desirable, mud-tolerant species predominate, lowering the quality of the fishery. Although precise concentrations of inorganic solids having varying degrees of effects on fishes have not been established, meaningful approximations can be made: [9]

Average Sediment Load	Impact
0- 25 mg/l	No harmful effects on fisheries
26-100 mg/l	Good to moderate fisheries
101-400 mg/l	Unlikely to support good fisheries
Above 400 mg/l	Poor fisheries

ESTIMATING POLLUTION LOADS

Potential pollutant contributions to surface and ground waters from agricultural sources are dependent upon topographic, meteorological, and hydrologic parameters. Associated with each different land use and type, there are different potential pollutants available for transport to receiving waters. Climatic conditions have a strong bearing upon the flow of pollutants from their source to a receiving body of water. Extensive study and monitoring are being undertaken in the study area to more accurately describe these factors. Other loading factors are presented in this section. Estimating loads and load variations is a difficult process because of the many interrelationships in the natural system, the many variables involved, and the general lack of extensive long-term data to define the interrelationships and relate observed loadings to the many variables.

Selected observed loading factors for agricultural waste loads are summarized in Table 6. The table includes loadings and concentrations reaching surface and ground water from agricultural lands, woodlands, and animal waste facilities.

The utility (though not the accuracy) of the information provided in this section can be demonstrated by a simple example. Consider a 100 acre watershed that drains to a 10 acre lake. The land use in the watershed consists of 10 acres of forest, 20 acres of pasture, and 70 acres of cropland. The following calculations can be made:

1. Using Table 1 data for Lake Wingra, the total nitrogen and phosphorus inputs from the air to the Lake would be 206 pounds total nitrogen and 9 pounds total phosphorus in one year.

2. Using data from Table 3, the erosion would be 750 pounds/year for the forest; 15,000 pounds/year for the pasture; and 1,050,000 pounds/year for cropland for a total erosion of 1,065,750 pounds/year. In addition, using data from Table 4, the amount of the erosion reaching the Lake would be about 10,890 cubic feet/year. At a water content of 70 percent, this would be about 555,400 pounds/year of dry sediment (density of 170 pounds/feet^3 assumed). The sediment delivery ratio would be about 0.52. Finally, using data from Table 5, the total nitrogen and total phosphorus loads assuming 0.2 grams TN/200 grams dry sediment and

[9] *U. S. Environmental Protection Agency, "State-of-the-Art: Sand and Gravel Industry," EPA-660/2-74-066, June 1974.*

Table 6

COMPARATIVE MAGNITUDE OF AGRICULTURAL NONPOINT WASTE LOADS

Location	Land Use	Loading Rate (pounds/acre/year) COD	TN	NO_3-N	TP	TSS	Notes	Reference
South Dakota	Corn and Oats	43	0.81	0.33	0.27	25.5	Rain and snow runoff	L. L. Harms; J. N. Dornbush; and J. R. Andersen, Physical and Chemical Quality of Agricultural Land Runoff, U.S. Environmental Protection Agency, Project No. R-800400, 1973.
South Dakota	Pasture	25	1.00	0.36	0.22	10.5	Rain and snow runoff	Ibid.
South Dakota	Alfalfa	12	0.65	0.21	0.09	3.6	Rain and snow runoff	Ibid.
Ohio	Continuous Corn	--	0.59	--	0.02	--	Snow leachate to groundwater	R. A. Loehr, "Characteristics and Comparative Magnitude of Nonpoint Sources," JWPCF, Volume 46, No. 8, August 1974.
Ohio	Continuous Corn	--	0.31	--	0.04	--	Rain leachate to groundwater	Ibid.
Ohio	Rotation Corn	--	0.06	--	0.03	--	Snow leachate to groundwater	Ibid.
Ohio	Rotation Corn	--	0.16	--	0.02	--	Rain leachate to groundwater	Ibid.
Ohio	Rotation Alfalfa	--	3.50	--	0.07	--	Snow leachate to groundwater	Ibid.
Ohio	Rotation Alfalfa	--	0.00	--	0.00	--	Rain leachate to groundwater	Ibid.
Wisconsin	Mixed	--	5.90-8.10	--	0.37-0.41	--	Rain and snow runoff	Ibid.
Wisconsin	Mixed	--	1.07	--	0.10	--	Leachate to groundwater	Ibid.
Wisconsin	Mixed	--	3.93	--	1.16	--	Runoff—no manure spreading	Ibid.
Wisconsin	Mixed	--	11.33	--	2.59	--	Runoff—manure spread in winter follows .75 inch rain (15 tons/acre)	Ibid.
Wisconsin	Mixed	--	3.93	--	0.71	--	Runoff—manure spread in spring (15 tons/acre)	Ibid.
Wisconsin	Mixed	--	0.03	--		--	Unfertilized field runoff	S. Lin, "Nonpoint Rural Sources of Water Pollution," Circular III, Illinois State Water Survey, 1972.
South Dakota	Beef Feedlot[a]	14,316	982.00	--	298.00	18,315.0	Runoff of 11.75 acres on 6 percent slope	Ibid.
South Dakota	Dairy Feedlot[a]	12,770	1,012.00	--	391.00	20,678.0	Runoff of 0.32 acre on 4 percent slope	Ibid.
Nebraska	Beef Feedlot	--	400.00	--	178.00	12,500.0	Snowmelt runoff (200 square feet/ head) (1969)	Loehr, "Characteristics and Comparative Magnitude," August 1974.
Nebraska	Beef Feedlot	--	196.00	--	29.00	6,515.0	Rainfall runoff (200 square feet/ head) (1969)	Ibid.
Minnesota	Forest	--	1.80	1.40	0.10	--	Rainfall runoff	Ibid.

Location	Land Use	Concentration (mg/l) COD	TN	NO_3-N	TP	TSS	Notes	Reference
South Dakota	Corn and Oats	49	2.10	1.00	0.44	51	Snow runoff	L. L. Harms; J. N. Dornbush; and J. R. Andersen, Physical and Chemical Quality of Agricultural Land Runoff, U. S. Environmental Protection Agency, Project No. R-800400, 1973.
South Dakota	Corn and Oats	148	2.60	1.50	1.05	1,021	Rainfall runoff	Ibid.
South Dakota	Pasture	69	3.30	0.90	0.67	18	Snow runoff	Ibid.
South Dakota	Pasture	49	1.70	0.40	0.47	38	Rainfall runoff	Ibid.
South Dakota	Alfalfa	62	2.80	0.80	0.43	42	Snow runoff	Ibid.
South Dakota	Alfalfa	22	0.80	0.30	0.35	40	Rain runoff	Ibid.
Kansas	--[b]	4	--	0.10	0.18-0.30	--	Stream quality prestorm	G. A. Stoltenbert "Water Quality in an Agricultural Watershed," paper presented at Twentieth Annual Conference on Sanitary Engineering, University of Kansas, Lawrence, Kansas, January 1970.
Kansas	--[b]	20	--	9.00-10.00	2.40-4.00	--	Stream quality poststorm	Ibid.
Illinois	Mixed	--	--	4.50-22.00	--	--	Farm drain tiles	Lin,"Nonpoint Rural Sources," 1972.
Nebraska	Beef-feedlot	41,000	2,100.00	17.00	290.00	--	Snowmelt runoff	Loehr, Characteristics and Comparative Magnitude, August 1974.
Nebraska	Beef feedlot	3,100	920.00	10.00	360.00	--	Rainfall runoff	Ibid.
Minnesota	Forest	--	0.54	0.53	0.04	--	Rainfall runoff	Ibid.

[a]*Estimate 5 percent of total waste generated leaves feedlot in surface runoff.*

[b]*Drainage area of 1,340 acres: 66 percent corn and wheat, 26 percent pasture, 8 percent woods. Coliforms increased with runoff and was related to flow and turbidity in the sited study.*

Source: Stanley Consultants

0.1 grams TP/100 grams of dry sediment would be 1,110 pounds total nitrogen and 550 pounds total phosphorus added per year.

3. Using data from Table 6 with total nitrogen loading rates of 1 pound/acre/year for pasture, 1.8 pounds/acre/year for forest and 7.0 pounds/acre/year for cropland, and total phosphorus loading rates of 0.22 pounds/acre/year for pasture, 0.1 pound/acre/year for forest and .39 pound/acre/year for cropland, total loadings to the Lake from runoff would be 528 pounds total nitrogen/year and 33 pounds total phosphorus/year using this approach.

These alternative methods of calculating nutrient loadings from agricultural land runoff indicate the difficulty of using generalized loading rates to determine the effects of land use on water quality.

The use of measured loadings has been made near the Region at White Clay Lake [10] Results indicate the following loading factors:

	Total Nitrogen (pounds/acre/year)	Total Phosphorus (pounds/acre/year)
Precipitation (on Lake)	5.0 - 6.6	1.2 - 1.6
Surface Runoff from Upland Areas	3.9 - 4.7	.5 - .6
Ground Water Input to Surface Water	1.2	0.1
Total Load to Lake	10.6 - 11.1	2.6 - 2.7

Additional inputs to White Clay Lake due to animal wastes (about 43 percent of total nitrogen load and 66 percent of total phosphorus load) and septic tank drainage (less than 1 percent of total load) were observed. Watershed studies similar to this project are the best method to assess land use and water quality relationships, but involve considerable expense and time to undertake.

[10] *Berkowitz, et al, "White Clay Lake Watershed Water and Related Land Resources Management Study,"*

Chapter III

METHODS TO CONTROL SOIL EROSION AND SEDIMENT DELIVERY

INTRODUCTION

The information provided in Chapter II indicates that sediment is a major pollutant in itself and carries with it phosphorus and other potentially harmful substances that can impair water quality. Few structural controls involving collection and treatment are applicable to the sediment problem; therefore, nonstructural controls must be devised. This chapter reviews nonstructural controls for sediment and erosion control.

The overall control concept requires understanding that surface water pollution is the result of the following two factors:

1. Accumulation of pollutants on the surface of the earth.

2. Conveyance of pollutants to a waterway by precipitation runoff.

The control of waste sources then must focus on:

1. Elimination or reduction of pollutants introduced to the ground surface.

2. Removal of these pollutants before they can be carried away to waterways.

3. Control (or treatment) of surface runoff.

4. Control of soil to reduce erosion and sediment transport of pollutants.

Control of surface runoff is perhaps the most appropriate control for reducing sediment loading on surface waters. Most erosion control practices used in the past several decades operate physically through their effects on controlling the amount, depth, and/or velocity of surface runoff. Use of vegetative cover to prevent initial erosion, instead of restricting the distance eroded materials can travel, is also an effective control practice.

SOIL EROSION CONTROL METHODS

Soil erosion and sedimentation are naturally and continually occurring processes which shape the earth's surface over a long period of time. The degree of soil erosion depends upon soil characteristics and topography, land cover conditions, and regional rainfall characteristics. Only in more recent geologic times has man accelerated this natural process by removing native protective vegetation, disturbing the land surface and thereby changing hydrology. Removal of vegetation subjects soil to the two erosive forces: wind and water. Water causes the greater problems by carrying soil particles to waterways where it becomes the nation's major nonpoint pollutant, sediment. Soil carries with it fertilizers and other chemicals, makes streams turbid, and fills reservoirs. Wise land use and management are the two keys which control runoff and erosion to reduce pollution from this nonpoint source.

Water can cause sheet, rill, and gully erosion. Generally, a combination of agronomic and supporting practices is required to reduce the soil loss to any specific limit. The severity of the erosion hazard and effectiveness of each of the various practices that can be adapted to the situation dictates the combination needed. Erosion hazards can differ greatly within a relatively small geographic area. Use of a specific practice may be limited by soil or topographic constraints at a particular site. For these reasons, control practices can be most accurately prescribed on an individual field basis. General descriptions, costs, and effectiveness of practices can be evaluated on a regional basis to indicate types of controls that are applicable in the Region, the potential reduction of potential pollutant loadings on surface waters that may be expected by using the controls, and the relative cost of achieving those reductions.

To protect agricultural land from soil erosion problems, vegetative and mechanical conservation practices can be employed. These practices are conservation tillage, crop rotations, contouring, contour strip cropping, terraces, grass waterways, diversions, water and grade control structures, cover crops, pasture and hayland establishment and management, and critical area protection.

Conservation Tillage

Conservation tillage is an agronomic system which limits the number of cultural operations to those that are properly timed and essential to produce a row crop and prevent soil damage. In addition to reducing erosion by wind and water, conservation tillage retards deterioration of soil structure, reduces soil compaction and formation of tillage pans, and improves soil aeration, permeability, and tilth. Conservation tillage can be accomplished by various systems. In order for conservation tillage to be effective, the farmer must understand not only what he is doing, but why he is doing it. Three important objectives guide the design of conservation tillage practices: 1) to protect the soil during the winter by planting a cover crop or by leaving the preceding year's crop residue on the surface; 2) to make as few trips as possible over the field, and 3) if a seedbed is prepared, to leave the soil surface as rough as possible between the rows. Leaving crop residues on the surface during the spring and early summer rainstorm season is of great value in reducing erosion. Although conventional tillage implements can be used in many combinations to perform conservation tillage with various degrees of effectiveness, six systems, four of which use specialized planting equipment, are well defined. The following six systems are applicable in southeastern Wisconsin.

Zero tillage: In implementing this system residue may be shredded or disked prior to initial seedbed preparation. A special planter using a fluted coulter or double disk openers cuts through residues of the previous crop ahead of the planter shoe and disturbs only the immediate area of the crop seed row (see Figure 1). No seedbed preparations precede this operation. After planting, no more than one cultivation is used. This cultivation is performed only when herbicides have not provided adequate weed control. The method is also called no tillage.

Chisel tillage: Residue may be shredded or disked prior to seedbed preparation. While zero tillage does not require a seedbed preparation, chisel tillage uses a chisel plow to break or loosen the soil without inversion, thereby leaving most of the crop residue on the surface for control of water and wind erosion (see Figure 2). Seedbed preparation and planting may or may not be accomplished in the same operation. Generally, the crop is cultivated only once or not at all depending on the effectiveness of herbicides.

Strip tillage: Residue may be shredded or disked prior to seedbed preparation. A special tillage instrument clears residue from a strip not wider than one-third of the distance between rows, leaving an untilled area with a protective cover of crop residue (see Figure 3). This method is similar to zero tillage except that the zero-till planter uses a coulter or single chisel to prepare the seed row and the strip till has a rotary tool. Planting and tillage are accomplished in the same operation. Usually, the crop is only cultivated once or not at all depending upon weed control problems.

Till planting: The residue may be disked or shredded before seedbed preparation. The seedbed is prepared by a special planter with trash bars that clear a strip over the old row by pushing the soil and residue aside (see Figure 4). A narrow planter shoe opens a seed furrow into which seeds are dropped. A narrow wheel presses the seed into firm soil, covering disked loose soil over the seed. This system is most effective when used on the contour or across the slope. Generally, the crop is cultivated once or not at all.

Figure 1

ZERO-TILLAGE PLANTING

Source: U. S. Department of Agriculture, Soil Conservation Service.

Figure 2

CHISEL TILLAGE PLANTING

Source: U. S. Department of Agriculture, Soil Conservation Service.

Figure 3

STRIP TILLAGE PLANTING

Source: U. S. Department of Agriculture, Soil Conservation Service.

Plow-planting: The residue may be shredded or disked prior to seedbed preparation. The seedbed is prepared by conventional spring plowing with moldboard plow. The seed is planted directly in plowed ground with no secondary tillage. Planting and plowing can be done in the same operation or as two separate operations. Generally, the crop is cultivated once.

Wheel-track planting: Crop residue may be shredded or disked prior to seedbed preparation. This system is similar to plow-planting, but is not restricted to freshly plowed ground. Planting is done in the wheel tracks of the tractor or a planter. Plowing and planting are performed in two separate operations. Generally, only one cultivation is used.

Concluding Remarks—Conservation Tillage: The above-described conservation tillage systems have several advantages. They are:

1. Similar and/or somewhat lower cost than conventional tillage because the systems require fewer tillage operations and less equipment use.
2. The rough porous surface produced by the system provides detention storage for water to assist infiltration.
3. More water can be adsorbed before runoff and erosion can begin.
4. Mulch protects soil from raindrop impact and reduces crusting and surface sealing, thereby enhancing infiltration.
5. Mulch slows velocity of runoff and lowers its capacity to carry soil or cause gully erosion.

Figure 4

TILL PLANTING

Source: U. S. Department of Agriculture, Soil Conservation Service.

6. Mulch protects soil from wind erosion and helps retain soil moisture.
7. Fall chiseling or disking of corn stalks will help speed drying of soil in spring so that planting can be done earlier than with moldboard plow systems used in spring.
8. Deep tillage with a chisel plow can help shatter any existing plow pan produced by the moldboard plow.
9. The reduced disturbance of the soil may deter the microbiological destruction of soil organic matter helping to retain soil organic matter.

These systems also have several disadvantages. They are:

1. Planters must be equipped to plant in crop residues.
2. Obtaining packing for good soil to seed contact is more difficult than with conventional tillage methods. Seed germination and seedling growth are slower because the soil warms up later in the spring.
3. Crop residues may interfere with herbicides or cultivation, resulting in a more severe weed problem.
4. Disease and insect problems may be increased.
5. Lime and fertilizer may accumulate near the surface and lead to shallow root growth and underutilization of applied nutrients.
6. Decreased yield potential.
7. An initial capital outlay for the specialized equipment used in some of the systems is required.
8. The systems generally require greater use of pesticides and herbicides than conventional systems based on the moldboard plow.

The effectiveness of conservation tillage systems for erosion control begins with the residue left by the preceding year's crop. Fields with 6,000 pounds per acre of corn residue on the soil surface planted by no tillage methods have 90 percent less water erosion than conventionally planted corn fields.[1] Chisel planting methods with 6,000 pounds of residue reduce erosion by 70 percent.[2] More than 6,000 pounds does not increase the effectiveness significantly and as little as 3,000 pounds

---

[1] *Mulch Tillage in Modern Farming, Leaflet 554, U. S. Department of Agriculture, Washington, D. C., 1971.*

[2] *Ibid.*

is still effective. Leaving the crop residue mulch on the surface has reduced soil loss more than 75 percent in tests in Wisconsin.[3]

Table 7 shows soil losses from two soils occurring in southern Wisconsin using different tillage methods. Rules of thumb on the amount of residue left include one ton of residue produced for each yield of 35 bushels of corn, 20 bushels of wheat, 40 bushels of oats, and 40 bushels of soybeans.[4]

Crop Rotation

Crop rotation is a cropping system in which row crops, small grains, and grassland are grown in a planned sequence to reduce soil erosion. This sequence may be used on an entire field or as strips on one field. Sod-based rotations reduce soil erosion and direct runoff. Soil loss from a good quality grass and legume meadow is negligible. When the sod is plowed, residual effects improve infiltration, leaving the soil less erodible. The effects of the sod are greatest during the first year, but are also significant during the second year. With good fertility management, annual soil losses from four-year rotations of wheat-hay and two years of conventionally planted corn usually average about one-third of those from conventionally planted continuous corn.

Rotating two kinds of row crop or row crop and small grain is not so effective as the sod-based systems, but may aid in control of some diseases and pests, and usually reduces the amount of herbicides required. Small grain seeded in disked corn residues loses from 50 to 70 percent less soil than grain planted on a clean seedbed.[5]

Advantages of this system include:

1. Reduced pesticide, herbicide, and fertilizer use on a given field usually occurs.
2. The system is easy to implement and is widely accepted.

Disadvantages of the system include:

1. The major reason for the long-term soil loss reduction is reduced erosion from the periods of grassland or small grain cover, and the erosion from row crops is only slightly reduced during the years when row crops are grown.
2. The system is most applicable on farms where both row crops and grassland are needed in the farming operation.

Contouring

Contouring is a planting practice in which the crop rows follow the land contours across the slope. The average soil loss reduction from contouring is about 50 percent on moderate slopes but less on steeper slopes.

The advantages of contouring are:

1. Erosion control for moderate rainstorms.
2. Greatest effectiveness on 2 to 8 percent slopes.

---

[3] *"No Nonsense Guide to No-Till Farming," Allis Chalmers, Farm Equipment Division, Milwaukee, Wisconsin.*

[4] *Allen County Soil and Water Conservation District, Environmental Impact of Land Use on Water Quality, Operations Manual for the Black Creek Study, Maumee River Basin, Allen County, Indiana, National Technical Information Service PB 235 526, March 1974.*

[5] *B. A. Stewart et al, Control of Water Pollution from Cropland, Volume 1, A Manual for Guideline Development, Office of Research and Development, Environmental Protection Agency, EPA 600/2-75-026a, February 1975.*

Table 7

EFFECT OF CONSERVATION TILLAGE ON SOIL LOSSES IN WISCONSIN

Location, Soil and Slope	Experimental Conditions	Tillage Practice	Measured Soil Loss (tons/acre)
Madison, Wisconsin; Miami silt loam, 6 percent slope	Simulated rainfall; noncontoured plots	Conventional Residue Left	22.30 6.70
Madison, Wisconsin; Miami silt loam, 9 percent slope	Natural rainfall; contoured plots	Conventional Residue Left	1.42 0.01
La Crosse, Wisconsin; Fayette silt loam, 16 percent slope	Natural rainfall; contoured plots	Conventional Residue Left	2.00 0.03

Source: "No Nonsense Guide to No-Till Farming," Allis Chalmers, Farm Equipment Division, Milwaukee, Wisconsin.

The disadvantages of contouring are:

1. The practice is ineffective for severe rainstorms.

2. On long slopes, the practice needs to be supported by terraces or runoff diversions.

3. Following field contour lines with large equipment is time consuming and point rows are often encountered.

4. With poorly drained soils, contouring may aggravate wetness problems.

Contour Strip Cropping

Contour strip cropping is a method of growing crops in a systematic arrangement of strips or bands on the contour of a slope to reduce water erosion and runoff (see Figure 5). High quality sod strips (100 to 125 feet wide) have filtered 75 percent or more of the suspended soil from the runoff from the cultivated strips. Strip crop systems using a four-year rotation, two years of meadow, one of row crop, and one of small grain in which new meadow is established reduce soil loss to about half of the average for the same rotation contour farmed without the alternating strips, or about 25 percent of the rotation average with the rows up and down a moderate slope. Recommended strip widths are based on slope categories. These categories are shown in Table 8.

Actual widths within these categories can be adjusted to fit machinery sizes. If contour strips are installed and maintained on a 0.5 to 1 percent grade, they can be used on slopes as steep as 16 percent. The system is most applicable for farmers who need both row crops and hay in their farming operations.

Figure 5

CONTOUR STRIP CROPPING

Source: U. S. Department of Agriculture, Soil Conservation Service.

Critical Area Protection

Critical area protection is the stabilization of highly erodible or severely eroded areas by planting vegetation such as trees, shrubs, vines, grasses, or legumes. Critical areas include construction sites, highly eroded or gullied areas, sand blowouts, ditch bank sideslopes, ditch berms and spoils, surface-mined areas, development land needing permanent vegetation, and disturbed areas needing temporary cover. The protection procedure generally involves some earthwork prior to seedbed preparation, liming, fertilizing, and planting.

Cover Crops

Cover crops are crops of close growing grasses, legumes, or small grain used primarily for seasonal protection and for soil improvement. The crop usually occupies land for a period of one year or less. The purposes of the cover crop are to provide vegetative protection from soil erosion by wind and water during periods when the major crops do not furnish adequate cover, to add organic material to the soil, and to improve infiltration, aeration, and tilth.

Depending on weather conditions in any given year, a cover crop may be a help or a hindrance. If the soil wetness in the spring is a problem, the early growth of a wheat cover crop can enable earlier corn planting by removing excess water from the soil. Conversely, if soil moisture supplies are critical, water used for growth of the winter cover crop may reduce the amount of water available to the primary crop later in the growing season and thereby lower crop yields. An example of a cover crop is spring oats planted in the fall after harvesting a row crop. The growing oats freeze, but the tops protect the soil during the winter.

Pasture and Hayland Establishment and Management

Pasture and hayland establishment and management is the planting or replanting of long-term stands of adapted species of perennial, biennial, or reseeding forage plants. Management is the proper treatment and use to prolong the life of desirable forage species and maintain the quality and quantity of forage to provide soil protection and to reduce water loss.

Table 8

RECOMMENDED MAXIMUM CONTOUR STRIP WIDTHS FOR VARIOUS SLOPES

Slope Category (percent)	Strip Width[a] (feet)
2-4	100
4-7	85
7-12	70
12+	50 - 60

[a]A 20 percent tolerance is acceptable.

Source: U.S. Soil Conservation Service Technical Guide for Illinois, U.S. Department of Agriculture, September 1970.

The establishment of pastures and hayland requires a planned pasture program. The goal should be to provide a full season of forage. Two or more different pasture mixtures may be needed in a system to achieve this goal. Other considerations are the needs for a given herd size and the carrying capacity of the pasture.

Pasture management techniques are controlled or rotational grazing, fertilization, dispersal of water supplies, and dispersal and occasional relocation of salt, mineral, and supplemental feed sites. These items are discussed further in Chapter 5.

Terracing

A terrace system is a series of earth embankments or a ridge and channel constructed across the slope at a suitable spacing. Terraces reduce slope length by dividing overall slope into segments. Shortening the slope length reduces the soil loss from strips between the terraces, and up to 80 percent of the soil that is moved from between the terrace strips is deposited in the terrace channels. The type of terrace system most applicable to the study area is the gradient terrace system. Gradient terraces carry collected runoff in a graded channel to an outlet. The outlets may be surface, such as grassed waterways, or subsurface, such as tile or pipe (see Figures 6 and 7).

Gradient terraces can follow the contour of the land or be constructed parallel to one another with an equal distance between terraces. To maintain the equal distance between terraces, cuts and fills are made in the terrace ridge. The cuts and fills expose subsoils that may lead to reduced yield, but topsoil can be stripped and replaced to minimize this problem. Terraces are generally established on uniform slopes that do not exceed 8 percent, but can be used on slopes as steep as 12 percent and although not generally practical, terraces have been used on slopes up to 20 percent.[6] Once slopes exceed 10 percent, terraces should be designed with grass back slopes.

Gradient terraces with blind tile outlets (bench terraces) furnish a high degree (over 85 percent) of erosion control by providing a ponding area behind the benches which acts as a sediment trap. The ponded water can lead to wet soil conditions in the field for low permeability soils and hamper farming operations. Draining by field tile can reduce this problem.

Spacing of terraces is similar to strip width requirements for contour strip cropping as described in Table 8. They are advantageous in areas where continuous row cropping is the preferred cropping practice.

Diversions and Dikes

A diversion is an individually designed graded channel with the supporting ridge on the lower side constructed across the slope (see Figure 8). Diversions can be used for many purposes including:

1. Diverting water away from active gully heads to stop erosion.

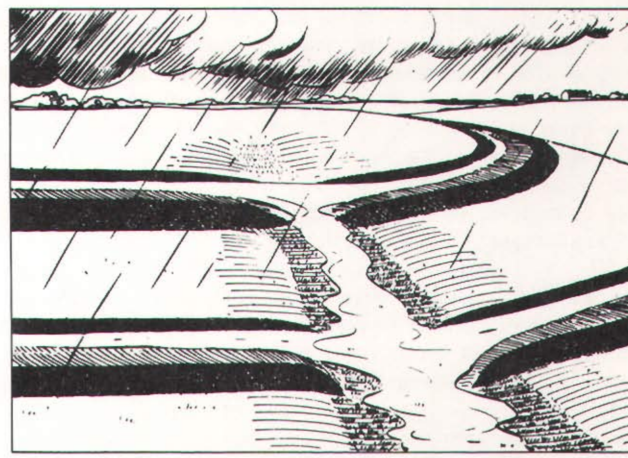
2. Reducing the length of slopes to supplement erosion resistant crops or contouring strip cropping on land continuously managed in row crops.

3. Breaking concentrations of water along gentle slopes and on undulating or warped land surfaces generally considered too flat or irregular for terracing.

4. Diverting water away from farm buildings and other improvements.

Figure 6

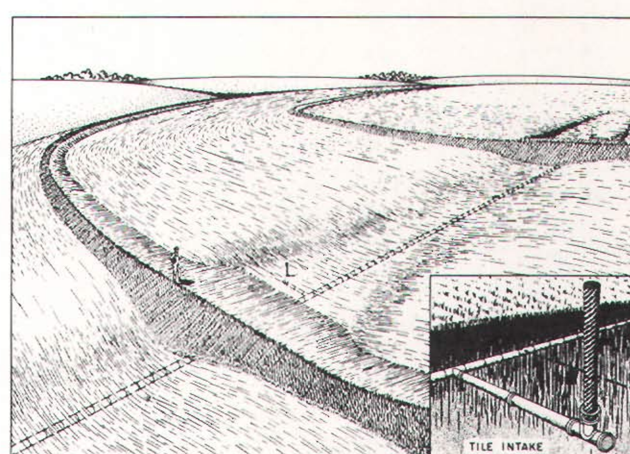
GRADIENT TERRACES WITH WATERWAY OUTLET



Source: Engineering Field Manual for Conservation Practices, U. S. Soil Conservation Service, 1969.

Figure 7

GRADIENT TERRACES WITH TILE OUTLETS



Source: Engineering Field Manual for Conservation Practices, U. S. Soil Conservation Service, 1969.

[6] *Engineering Field Manual for Conservation Practices, U. S. Soil Conservation Service, 1969.*

5. Protecting terrace systems by diverting headwater from the top terrace where topography or land ownership prevents terracing land above.

6. Protecting flat lands from the side hill runoff.

A special type of diking system has been used in the Region. A three to four foot tall dike with a six to eight foot top width is constructed in bottom lands near streams. The dike serves to protect the bottom lands from about a 10-year frequency flood while also allowing temporary ponding of runoff waters behind the dike. The ponding allows part of the sediment and associated nutrients to settle out on the farm land and not be carried into the stream. The system works as a sediment trap and captured sediment can be recovered. Vegetative filter strips along stream banks have also been used to remove sediment, but their overall effect on nutrient removal is unknown.

Water and Grade Control Structures

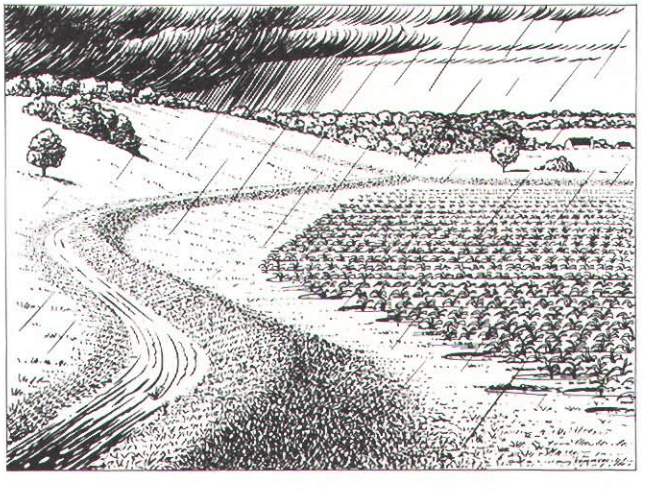
Water and grade control structures include drop spillways, box inlets, chute spillways, pipe drop inlets, debris basins, ponds, and other grade control structures. These structures supplement vegetative practices by reducing the grade in water courses, reducing the velocity of flowing water, storing water, trapping sediment, reducing peak water flows, and providing surface water inlets to ditches.

Grassed Waterways

Grassed waterways and outlets are natural or constructed waterways shaped to required dimensions and vegetated for safe disposal of runoff from fields, diversions, terraces, or other structures. Waterways can be used when added capacity and/or vegetative protection are needed to control erosion resulting from concentrated runoff. Disadvantages include establishment and maintenance problems, incompatibility with use of large farm equipment, and potential pollution from the use of herbicides to prevent the spreading of grass to row crops.

Figure 8

DIVERSION



Source: Engineering Field Manual for Conservation Practices, U. S. Soil Conservation Service, 1969.

CONTROL OF EROSION FROM WIND

Wind erosion results in water pollution when eroded soil particles are blown into drainage ditches, streams and lakes, or are dropped back to the earth where they are susceptible to water erosion. In southeastern Wisconsin this problem is generally a minor problem compared to water erosion. The problem manifests itself primarily on cultivated organic and sandy soils and on fall-plowed heavy-textured soils. The extent of wind erosion is a function of wind velocity and the character of the soil surface over which the wind passes. Most wind erosion control practices coincide with measures used to conserve moisture and control water erosion.

Major factors affecting wind erosion are soil cloddishness, surface roughness, windspeed and direction, soil moisture, field length, and vegetative cover. Considering these factors, the five basic principles of wind erosion control are to:

1. Establish and maintain vegetative or nonvegetative cover to protect the soil.

2. Produce, or bring to the soil surface, aggregates or clods large enough to resist the wind forces.

3. Roughen the land surface to reduce wind velocity and trap drifting soils.

4. Reduce field width along the prevailing wind direction (westerly in winter and southerly in summer) by establishing wind barriers or trap strips at intervals to reduce wind velocity and soil avalanching.

5. Level or bench land where economically feasible to reduce effective field widths and erosion rates on slopes and hilltops where wind forces are maximum.

The usefulness of these principles varies with land, climate, soil, and land use conditions. Most of the desired effects can be accomplished by measures discussed under water erosion. For example, conservation tillage practices leave the soil surface rough between the rows and provide protection with crop residue. An Ohio study[7] showed the effectiveness of no-tillage for controlling wind erosion. No-tillage corn was planted adjacent to plowed or strip rotary tilled corn on a sandy knoll. During one severe windstorm, as much as 130 tons per acre of sand movement was measured on the plowed area as compared to about two tons per acre on the no-till. Terracing and strip cropping reduce field widths and cover crops provide vegetative protection.

However, one measure not previously mentioned is planting shelterbelts of shrubs and trees in one to 10 rows. The effectiveness of a barrier depends on the wind velocity and direction, and on the shape, width, height, and porosity of

[7] *"No Nonsense Guide," Allis-Chalmers.*

the barrier. The wind speed blowing at right angles to a shelterbelt is reduced 70 to 80 percent near the belt, about 20 percent at a distance 20 times the height of the belt, and only about 2 to 5 percent at a distance 30 times the height of the belt.[8] Other barriers used for wind erosion control provide protection for distances ranging from one to 18 times their height, depending on the type used.[9] Temporary protection can be provided by artificial barriers, such as snow fence and earthen banks.

CONTROL OF STREAMBANK EROSION

Although sediment produced by stream bank erosion is not a major contributor to water quality degradation in southeast Wisconsin, the controls for this source are presented below. Stream bank protection includes stabilizing and protecting banks of streams or excavated channels against scour and erosion by vegetative or structural means or combinations of both.

The general types of bank protection measures are:

1. Measures which retard flow along the bank and thereby promote deposition.
2. Measures which through some form of bank cover protect the bank from direct erosion and scouring.

To determine the type of bank protection that should be used, several considerations must be taken into account.[10] These considerations are:

1. The size of the watershed draining into the stream.
2. The expected runoff and flood peaks.
3. The expected duration of flood flows.
4. The soil materials at the site.
5. The size and shape of the existing channels.
6. The nature of flow in the stream (continuous or intermittent).
7. The climatic conditions of the area.
8. The degree of protection required.
9. The expected debris load carried by the stream.
10. The causes of existing meandering and erosion such as fallen trees deflecting the water from its normal direction of flow; trees or brush growing on the inside of the curve deflecting water against the cutting bank; water from a waterway or smaller stream entering the channel and depositing sediment, thus deflecting water against the cutting bank; bedload drifts; ice drifts; and damage to banks by livestock.

The selection and design of stream bank protection measures is a complex process. Measures include channel clearing and snagging, vegetation, jetted willow poles, tree revetment, piling revetment, jacks, brush mat revetment, and rock riprap. The measures are simple in design and applicable to smaller streams (see Figure 9).

Channel clearing and snagging is the removal of sediment bars, snags, stumps, debris drifts, trees, brush, and objectionable vegetation that disturb the smoothness of flow. Trees on the bank which are in danger of undercutting and falling into the channel should be cut off and removed. Trees which might collect debris and ice drifts along the channel banks should also be removed. Vegetation growth on the banks such as brush and grasses may be trimmed but is generally left for bank protection.

Vegetation is used most successfully above the waterline on properly sloped banks. It should also be used behind revetments and jetties in areas where silt deposition occurs, on banks above design flows, and on slopes protected by brush mats. Many species of shrubs or trees are suitable for streambank protection plantings.

Jetted willow poles along the stream bank can provide a degree of stream bank protection especially at stream bends. Willow cuttings from willows growing along the stream are driven into the shoreline to extend two to three feet above the ground line. They can be supplemented with plantings of willow cuttings or erosion resistant plants. This type of protection is adapted for smaller streams where ice damage is not a problem.

A pervious revetment made from whole trees cabled together and anchored by dead ones buried in the bank can be used as stream bank protection. Trees having a trunk diameter of 12 inches and larger are required to provide a good barrier. The best type is those that have a brushy top. This type of revetment should not be used where trees could do severe damage to bridges or other structures if they break loose during a flood. Trees should be laid along the bank with the butts upstream, overlapping enough to ensure continuous protection of the bank. These have a limited life and must be replaced periodically. This is especially true where heavy ice flows occur, doing considerable damage to the trees. Bank stability can be improved by planting trees and shrubs above the normal water level. Planting should be delayed until the trees have silted in and deposits formed behind them. This type of protection is not adapted to general streams where channel width will materially be reduced by placement of the trees. However, it is well suited to conditions where water at the toe of the slope is deep. The reduction in channel capacity caused by tree placement must be considered.

---

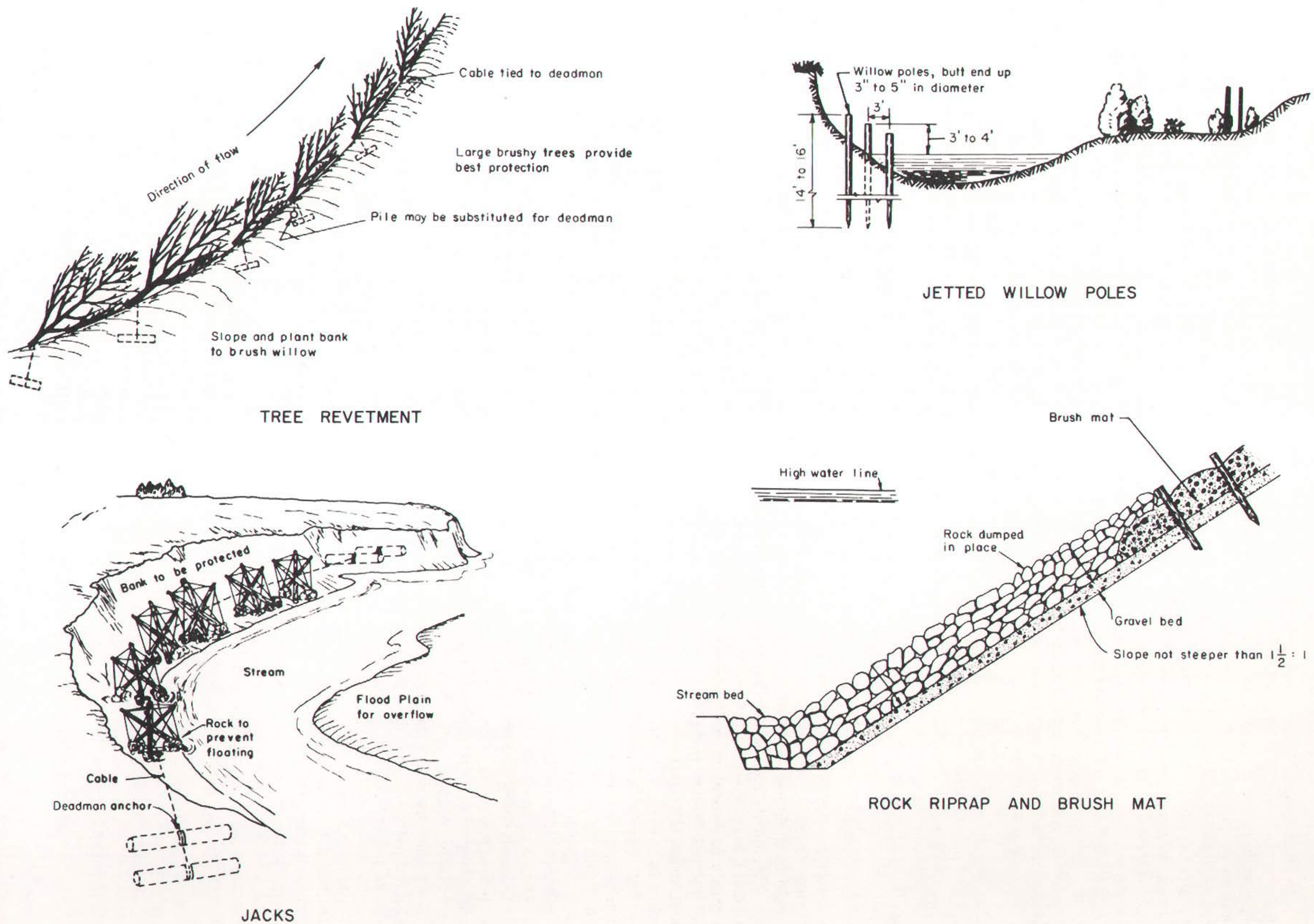
[8] *Methods for Controlling Water Pollution from Agricultural Nonpoint Sources*, *U. S. Environmental Protection Agency, EPA 430/9-73-015, October 1973.*

[9] *Ibid.*

[10] *Engineering Field Manual*, *U. S. Soil Conservation Service.*

Figure 9

SHORELINE EROSION CONTROL MEASURES



Source: Engineering Field Manual for Conservation Practices, U. S. Soil Conservation Service, 1969.

A continuous piling revetment with woven wire is a common type of protection. Where stream bank depth next to the bank is in excess of three to four feet, timber pilings are spaced from six to eight feet on center and driven to a depth so as to extend below the anticipated depth of maximum scour. A heavy grade of woven wire is fastened to the stream side of the pile. The wire collects debris and trash, forming a permeable wall which reduces the velocity on the bank side. If stream bed scour is anticipated, the woven wire is extended horizontally along the stream bottom for a distance at least equal to that anticipated depth of scour. Concrete blocks or other weights are attached to the bottom at regular intervals. As scouring occurs, the weights cause the wire to settle in a vertical position along the face of the pile.

"Jacks" are another method of stream bank erosion control. Jacks are constructed with three poles 10 to 16 feet in length. The poles are crossed and wired together at the midpoints. The ends are then tied together with wire. Jacks should be spaced no farther apart than one jack space and are held in place by a cable which is anchored to the bank by deadmen (logs buried in bank).

Brush mat revetments are good stream bank erosion protection measures where willow, brush, and rock are available in quantities sufficient to construct the revetments. The mat is constructed by first placing the rock toe so that it may be used as a base for the brush mat. The rock should be carried to the low point of the channel and be at least 18 inches thick to remove the danger of displacement during flood flows. The rock toe is not practical in streams subject to channel scour during flood flows. The slope banks should be planted before the brush matting is applied. The best time to do this is in the spring. Brush should be placed over the exposed soil as soon as possible after the bank is planted. Brush willow is the best material and should be laid shingle-fashion with the butts pointing up the bank. Brush should be straight enough to lie flat on the bank and the mat should be 6 to 18 inches thick depending on the size of the stream and the ice hazard. The mat is held in place by driving stakes at an angle crossing each other in pairs or by stakes driven into the ground about 2.5 feet on centers and interlaced with galvanized wire. After the wire is attached, the stakes are driven deeper to tighten the wire.

Rock riprap placed properly is an effective method of stream bed protection. The toe of the revetment must be securely established. The slope of the bank on which the riprap is applied should not be steeper than 1.5:1. A six inch gravel filter is placed on the bank prior to dumping the riprap in place. A minimum of hand labor should be used to eliminate pockets of finer materials that may flush out.

The effectiveness of stream bank protection measures is widely debated. Mass soil movements near the protection are reduced, but the measures may change stream flow patterns enough to adversely affect other areas.

SPECIAL CONSIDERATIONS FOR WOODLANDS

Although a well managed forest contributes few pollutants to the aquatic environment, the potential for generation of pollution from woodlands does exist. The quantities of pollutants discharged to streams and other water bodies reflect forest management and efforts made to control and minimize material movement.

If pollutants occur in runoff from forestlands, they generally have the same character and nature as pollutants generated by agricultural activities. Mineral soil, organic matter, and applied chemicals (fertilizer, pesticides, fire retardants) can be transported to surface water by runoff.

Fertilization of forests is a growing management practice in the Pacific Northwest Douglas fir region. However, this practice is not performed in southeastern Wisconsin. Two other chemicals applied to forestlands are fire retardants and pesticides. Fire retardants are not applied in southeastern Wisconsin, but a limited amount of pesticides is used. Princep; 2,4-D; and Amitrol are used for various types of vegetation control.

The major potential pollutant in forestland runoff in southeastern Wisconsin is sediment. Land protected by a forest canopy produces relatively small amounts of sediment. The production of large quantities of sediment is more likely to occur during timber harvesting in commercial forests. In southeastern Wisconsin timber is harvested from private and state lands. Approximately 0.75 million board feet of privately-owned timber are marked for harvest each year. Sixty to 75 percent of the marked timber is harvested. Because of the uneven aged stands, very little clear-cutting occurs. In the Kettle Moraine State Forest, about 300 acres (4,000 cords) in the pulpwood plantation were harvested in 1975. Cutters take two rows of trees and leave three rows or harvest about 40 percent of an area. The influence of forest cover on annual sediment yield is indicated in Table 9.

Current silvicultural management practices in the Region appear to be acceptable from a pollution control standpoint. Changes in current practices are not anticipated in the future.

Table 9

INFLUENCE OF FOREST COVER
ON ANNUAL SEDIMENT YIELD

Land Area With Forest Cover (percent)	Annual Sediment Yield (tons/square mile)
20	400
40	200
60	90
80	45
100	22

Source: U. S. Environmental Protection Agency, Processes, Procedures, and Methods to Control Pollution Resulting from Silvicultural Activities, EPA 430/9-73-010, U. S. Government Printing Office, October 1973.

COST AND EFFECTIVENESS OF CONTROLS

Effectiveness

The potential effectiveness of tillage systems and conservation practices used to reduce soil loss can be evaluated in two ways:

1. Estimate the actual soil loss in tons per acre per year by applying the universal soil loss equation to possible cropping systems.

2. Estimate the relative effectiveness (percent) of the possible cropping systems by comparing the cropping and practice factors used in the previously mentioned equation.

The universal soil loss equation ($A = R \times K \times LS \times C \times P$) estimates the average annual soil loss from sheet and rill erosion due to rainfall in tons per acre per year for a specific combination of rainfall (R), soil (K), topographic features (LS), crop system and cultural management (C), and supporting erosion control practices (P). A detailed discussion of this equation can be found in Agricultural Handbook No. 282, issued by the U. S. Department of Agriculture.[11] The equation does not account for soil losses due to snowmelt or wind erosion, is valid only for small areas since its emperical parameters were based on tests of small areas, and is mainly useful for cropland. The equation predicts erosion, not sediment yield, from cropland. Erosion from land uses other than row crops (that is, forests, pastures, and construction sites) can be estimated, but more research is needed to substantiate "C" values reported in the literature. Erosion from streambanks, road ditches, gullies, and land slides cannot be estimated using the equation.

In spite of its limitations, the equation can be used to demonstrate the relative effectiveness of alternative control practices.

Table 10 was developed using this equation for representative soils and slopes in the Region and shows the effect various management systems have on soil loss. Fall-plowed corn planted up and down the slope with residue removed was used as the benchmark practice and arbitrarily assigned a P value of 1. Based on this table, the most effective system of the examples is a six-year rotation planted on the contour with residue left on spring plowing. In all cases, this cropping management system reduces the soil loss to within the allowable soil loss limit. The limit is the maximum amount of soil loss in ton/acre/year that can be tolerated and still achieve the degree of conservation needed for sustained economic crop production in the foreseeable future with present technology. This system is not the only one which has the potential to sufficiently reduce soil loss. Other combinations and systems may also prove adequate.

Table 11 shows the relative soil loss reduction when changing from one cropping management system (System 1) to another (System 2) and the additional reduction that can be achieved by using the supporting practice on System 2. Comparisons show the relative difference of fall plowing versus spring plowing, residue removed versus residue left, conventional tillage versus various minimum tillage systems, and no rotation versus rotation. Contouring and terracing are applied to all situations except no-till. The greatest soil loss reductions occur when changing a conventional tillage system to a minimum tillage system.

The universal soil loss equation estimates soil movement on a land surface due to gross sheet and rill erosion caused by rainfall, but does not directly predict downstream sediment yield. Sediment yield equals the gross erosion including gully, streambank, and sheet and rill erosion, minus that which has been deposited enroute to the place of measurement. The sediment delivery ratio is defined as a ratio of sediment delivered at a location in the stream system to the gross erosion from the drainage area above that point. The sediment delivery ratio depends on such factors as physiography, size of the watershed, slopes, soil textures, and presence or absence of dams. These and other factors can cause sediment delivery ratios to vary widely, but limited data have shown that they vary inversely as the 0.2 power of the drainage area. Table 12 contains typical sediment delivery ratios for various size watersheds.

Reducing the delivery of sediment to surface waters may or may not affect the transport of agricultural chemicals to surface waters as discussed in Chapter 2.

Costs

The preceding discussion has dealt with the technical aspects of various controls. However, the economic aspects of these controls are a significant consideration for individuals making a decision on which available option to use. Realistically, the farmers' concern is maximization of his average net return over a period of time.

An example of costs and returns for selected options is shown in Table 13. These figures represent the costs and return for a 250 acre farm. Five options were used that limit the annual soil loss to less than five tons per acre per year. These options and their estimated soil losses under this hypothetical situation were:

	Estimated Soil Loss (tons/acre/year)
Contoured, zero tillage, corn	4.2
Contoured corn-corn-corn-wheat-meadow rotation	2.9
Terraced corn-strip tillage	3.6
Terraced corn-chisel planting	4.2
Terraced corn-soybean rotation-zero tillage	4.0

[11] *W. H. Wischmeir and D. D. Smith, Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains, Agricultural Research Service, U.S.D.A., May 1965.*

Table 10

COMPARISON OF ESTIMATED SOIL LOSSES USING VARIOUS TILLAGE SYSTEMS AND CONSERVATION PRACTICES ON REPRESENTATIVE STUDY AREA SOILS

Soil Type	Slope: Percent Slope	Slope: Slope Length (feet)	Slope: LS Ratio[a]	Soil Factor: K[b]	Soil Factor: T[c]	Soil Factor: T/K	Cropping Management System: Practice	Cropping Management System: P[d] Value	Cropping Management System: Crop, Rotation, and Management	Cropping Management System: C Factor[e]	Estimated Soil Loss (tons/acre/year)
Miami	6	300	1.20	0.37	3-2	8.1	Up and Down Slope	1	C-RdR-fall TP conv.	0.460	25.5
							Minimum Tillage	--	C-ST-4,000-6,000 pounds RdL	0.130	7.2
							Crop Rotation	--	R-R-G-M-M-M-RdL-Sp TP	0.087	4.8
							Contouring	.5	C-RdR-fall TP conv.	0.460	12.8
							Contour Strips	0.25	R-R-G-M-M-M-RdL-Sp TP	0.087	1.2
							Terracing	0.5	G-RdR-fall TP conv.	0.460	12.8
Casco	8	200	1.40	0.32	3-2	9.4	Up and Down Slope	1	C-RdR-fall TP conv.	0.460	25.7
							Minimum Tillage	--	C-ST-4,000-6,000 pounds RdL	0.130	7.3
							Crop Rotation	--	R-R-G-M-M-M-RdL-Sp TP	0.087	4.9
							Contouring	0.5	C-RdR-fall TP conv.	0.460	12.9
							Contour Strips	0.25	R-R-G-M-M-M-RdL-Sp TP	0.087	1.2
							Terracing	0.5	C-RdR-fall TP conv.	0.460	12.9
Fox	8	200	1.40	0.37	3-2	8.1	Up and Down Slope	1	C-RdR-fall TP conv.	0.460	29.8
							Minimum Tillage	--	C-ST-4,000-6,000 pounds RdL	0.130	8.4
							Crop Rotation	--	R-R-G-M-M-M-RdL-Sp TP	0.087	5.6
							Contouring	0.5	C-RdR-fall TP conv.	0.460	14.9
							Contour Strips	0.25	R-R-G-M-M-M-RdL-Sp TP	0.087	1.4
							Terracing	0.5	C-RdR-fall TP conv.	0.460	14.9
Elliott	6	200	0.95	0.37	3-2	8.1	Up and Down Slope	1	C-RdR-fall TP conv.	0.460	20.2
							Minimum Tillage	--	C-ST-4,000-6,000 pounds RdL	0.130	5.7
							Crop Rotation	--	R-R-G-M-M-M-RdL-Sp TP	0.087	3.8
							Contouring	0.5	C-RdR-fall TP conv.	0.460	10.1
							Contour strips	0.25	R-R-G-M-M-M-RdL-Sp TP	0.087	1.0
							(Terracing Not Applicable)				
Morley . . .	6	200	0.95	0.43	3-2	7.0	Up and Down Slope	1	C-RdR-fall TP conv.	0.460	23.5
							Minimum Tillage	--	C-ST-4,000-6,000 pounds RdL	0.130	6.6
							Crop Rotation	--	R-R-G-M-M-M-RdL-Sp TP	0.087	4.4
							Contouring	0.5	C-RdR-fall TP conv.	0.460	11.8
							Contour strips	0.25	R-R-G-M-M-M-RdL-Sp TP	0.087	1.1
							Terracing	0.5	C-RdR-fall TP conv.	0.460	11.8
Theresa . . .	5	200	0.76	0.37	3-2	8.1	Up and Down Slope	1	C-RdR-fall TP conv.	0.460	16.2
							Minimum Tillage	--	C-ST-4,000-6,000 pounds RdL	0.130	4.6
							Crop Rotation	--	R-R-G-M-M-M-RdL-Sp TP	0.087	3.1
							Contouring	0.5	C-RdR-fall TP conv.	0.460	8.1
							Contour Strips	0.25	R-R-G-M-M-M-RdL-Sp TP	0.087	0.8
							Terracing	0.5	C-RdR-fall TP conv.	0.460	8.1
Kewaunee . .	8	200	1.40	0.43	3-2	7.0	Up and Down Slope	1.00	C-RdR-fall TP conv.	0.460	34.6
							Minimum Tillage	--	C-ST-4,000-6,000 pounds RdL	0.130	9.8
							Crop Rotation	--	R-R-G-M-M-M-RdL-Sp TP	0.087	6.6
							Contouring	0.50	C-RdR-fall TP conv.	0.460	17.3
							Contour Strips	0.25	R-R-G-M-M-M-RdL-Sp TP	0.087	1.6
							Terracing	0.50	C-RdR-fall TP conv.	0.460	17.3
Manawa . . .	3	200	0.35	0.32	3-2	9.4	Up and Down Slope	1.00	C-RdR-fall TP conv.	0.460	6.4
							Minimum Tillage	--	C-ST-4,000-6,000 pounds RdL	0.130	1.8
							Crop Rotation	--	R-R-G-M-M-M-RdL-Sp TP	0.087	1.2
							Contouring	0.50	C-RdR-fall TP conv.	0.460	3.2
							Contour Strips	0.25	R-R-G-M-M-M-RdL-Sp TP	0.087	0.3
							(Terracing Not Applicable)				

NOTE: Rainfall factor = 125

[a] *B. A. Stewart et al, Control of Water Pollution from Cropland, Volume 1, A Manual for Guideline Development, Office of Research and Development, Environmental Protection Agency, EPA*

[b] *U.S. Soil Conservation Service Technical Guide for Illinois, U.S. Department of Agriculture, September 1970.*

[c] *Ibid. (Allowable soil loss in T/Acre/Year)*

[d] *Stewart, Control of Water Pollution from Cropland.*

[e] *U.S. Soil Conservation Service Technical Guide Rainfall "E. I." Distribution Curve No. 14. U.S. Soil Conservation Service Technical Guide for Illinois.*

Legend

C	*= Continuous corn*	*TP*	*= Turn plowed*
G	*= Small grain*	*ST*	*= Strip till*
M	*= Meadow*	*Z*	*= No till*
RdR	*= Residue removed*	*PP*	*= Plow-plant*
RdL	*= Residue left*	*Conv.*	*= Conventional*
Sp	*= Spring*	*R*	*= Row Crop*

Source: Stanley Consultants.

Table 11

COMPARISON OF RELATIVE EFFECTIVENESS OF TILLAGE OPERATIONS AND CONSERVATION PRACTICES

Cropping Management					Factor for Support Practice for System		
System 1[a]		System 2[a]		Soil Loss[e] Reduction (percent)			Soil Loss[f] Reduction (percent)
System	C Value[b]	System	C Value[b]		Practice	P Value[c]	
C-RdR-fall TP Conv.	0.46	C-RdR-Sp TP Conv.	0.44	5	Contouring - 6 percent slope Terracing - 9 percent slope	0.5 0.6	52 43
R-R-G-M-RdR-Sp TP Conv.	0.147	R-R-G-M-RdL-Sp TP Conv.	0.131	11	Contouring - 6 percent slope Terracing - 9 percent slope	0.5 0.6	54 46
C-RdR-fall TP Conv.	0.46	C-RdL-SP-PP	0.24	49	Contouring - 6 percent slope Terracing - 9 percent slope	0.5 0.6	74 70
C-RdR-fall TP Conv.	0.46	C-RdL ST	0.13	72	Contouring - 6 percent slope Terracing - 9 percent slope	0.5 0.6	85 83
C-RdR-fall TP Conv.	0.46	C-RdL Z	0.07	85	-- --	-- --	-- --
R-R-R-C-M-M-RdR-Sp TP Conv.	0.178	R-R-R-G-M-M-RdL-ST	0.065	63	Contouring - 6 percent slope Terracing - 9 percent slope	0.5 0.6	83 78
C-RdL-Sp TP Conv.	0.35	R-R-G-M-M RdL-Sp TP Conv.	0.101	71	Contouring - 6 percent slope Terracing - 9 percent slope	0.5 0.6	86 83

[a]*Crop, rotation, and management.*

[b]*Rainfall "E.I." Distribution Curve No. 14, U.S. Soil Conservation Service Technical Guide for Illinois, U.S. Department of Agriculture, September 1970.*

[c]*B. A. Stewart et al, Control of Water Pollution from Cropland, Volume 1, A Manual for Guideline Development, Office of Research and Development, Environmental Protection Agency, February 1975.*

[d]*4,000-6,000 pounds of residue.*

[e]*Reduction obtaining in going from System 1 to System 2.*

[f]*Reduction obtained by using the support practice with System 2 as compared to System 1 without a supportive practice.*

Source: Stanley Consultants.

Legend

C = Continuous corn
G = Small grain
R = Row crop
M = Meadow
RdR = Residue removed
RdL = Residue left
Sp = Spring
TP = Turn plowed
ST = Strip till
Z = No till
PP = Plow-plant

Table 12

TYPICAL SEDIMENT DELIVERY RATIOS FOR VARIOUS SIZED WATERSHEDS

Drainage Area (square miles)	Sediment Delivery Ratio
0.5	0.33
1.0	0.30
5.0	0.22
10.0	0.18
50.0	0.12
100.0	0.10
200.0	0.08

NOTE: These estimates should be used with judgment.

Source: B.A. Stewart et al, Control of Water Pollution from Cropland, February 1975.

In the calculations for Table 13, estimated soil loss for continuous corn without erosion control was 29 tons per acre per year. Nutrient use was less for the rotation options which use substantially less nitrogen fertilizer. Pesticides use is also lower for some options. For example, insecticide usage was 50 percent lower for the corn-soybean rotation and 25 percent lower for the corn-wheat-meadow rotation, than for other options. Although herbicide usage was highest for no-till, herbicides generally have less impact on the environment than insecticides. Except for the terrace strip till corn, returns from conventional tillage exceeded all other options. While returns were less where pollution control measures were employed, they were still competitive with the continuous corn, conventional tillage. In addition, no value was assigned to the fertilizer lost with the soil eroded from the conventional tillage, nor to the reduction in future crop yields as a result of the loss of topsoil. Nor were benefits included for the increased water quality resulting from use of the best soil conservation practices. The example serves to show the types of considerations involved in making farming decisions.

Table 13

ANNUAL COSTS AND RETURNS FOR SELECTED OPTIONS

Item	Straight Row	Contour		Terraced		
	C Conventional (in Dollars)	C No-Till (in Dollars)	C-C-C-W-M No-Till (in Dollars)	C Chisel (in Dollars)	C Strip (in Dollars)	CB No-Till (in Dollars)
Gross Revenue[a]	75,625.00	72,187.50	61,312.50	75,625.00	75,625.00	66,093.75
Costs						
Tractor (excluding fuel)[b]	3,430.25	3,066.46	3,426.24	3,238.69	3,066.70	2,887.79
Implements (excluding fuel)[b]	5,940.23	4,973.11	8,038.98	4,961.73	5,077.54	5,179.43
Fuel	1,432.85	1,113.92	1,427.16	1,267.69	1,113.92	937.36
Seed[c]	1,712.50	1,937.50	2,947.50	1,787.50	1,787.50	2,155.00
Fertilizer	7,912.50	7,912.50	4,452.50	7,912.50	7,912.50	4,782.50
Pesticides[d]	4,500.00	5,750.00	3,750.00	4,500.00	4,500.00	4,500.00
Labor[e]	1,803.75	1,178.12	1,659.12	1,568.12	1,348.75	885.62
Terracing[f]	--	--	--	1,725.00	1,725.00	1,725.00
Other	4,195.00	4,088.09	2,691.01	4,190.96	4,183.51	2,246.64
Land charge	18,020.00	18,020.00	18,020.00	18,020.00	18,020.00	18,020.00
Total costs	48,947.08	48,039.70	46,412.51	50,897.19	50,460.42	45,044.34
Net return	26,677.92	24,147.80	14,899.99	26,452.81	26,889.58	22,774.44

[a] *Yields used were 110 bushels/acre for conventional tillage corn; 105 bushels/acre for no-till; wheat 45 bushels/acre; soybeans 40 bushels/acre; hayland 4 tons/acre on a 250 acre farm.*

[b] *Straight line depreciation at 8 percent.*

[c] *No-till options require higher planting rates because seed mortality is higher.*

[d] *Reduced insecticide cost for wheat and meadow in the rotation. No insecticide included for soybeans so CB rotation has 50 percent cost of insecticides for continuous corn.*

[e] *Labor requirement estimated at 130 percent of tractor hour requirement. Cost per hour is $2.50.*

[f] *62,250 feet costing $0.60 per foot to construct and $0.06 per foot to maintain. Assumed 20-year economic life discounted at 8 percent p.a. interest. Assuming 50 percent Federal cost-sharing through ASCS program.*

Source: Stewart et al, Control of Water Pollution from Cropland, February 1975 and Stanley Consultants.

While costs are a significant consideration, a realistic observation is that no management decision is made entirely on the basis of economics. Other variables including risk; uncertainty; grower attitude, preference, and education; size of operation, work scheduling problems; climate; and tenure status also influence decisionmaking.

Historically, soil conservation practices have been advocated considering conservation as a means of maintaining the economic productivity of the land over a long time frame.

In water quality management planning, however, consideration must be given to the costs and potential pollutant load reduction that can be obtained by applying agricultural controls. Costs and potential pollutant load reduction refer to costs reduction. Table 14 summarizes the cost and effectiveness of agricultural controls discussed in this chapter. The costs were obtained by modifying information in an Allen County, Indiana, study[12] and using information obtained from personnel in the U. S. Soil Conservation Service field offices in Waukesha, Ozaukee, Walworth, and Racine Counties. The effectiveness is based on cropping management and conservation practice factors applicable to southeastern Wisconsin. When a conservation practice is implemented, it may or may not affect the immediate yield obtained from a field. Balanced against any immediate yield reduction must be considerations of long-term yield maintenance. Certain practices such as bench terraces and gradient terraces can allow a more intensive level of farming leading to increased yield, but the practice removes some land from production.

The cost data provided in Table 14 reflects the cost of adopting a conservation practice without consideration of revenue gains or losses that may occur due to changes in yield. These changes must be considered in selection of a practice for a specific site.

Cost-Effectiveness

A relative idea of the cost and effectiveness of alternative controls can be gained by analyzing the soil loss reduction that may occur from a practice versus the cost of that

[12] *Allen County Soil and Water Conservation District, Environmental Impact of Land Use on Water Quality, Operations Manual for the Black Creek Study, Maumee River Basin, Allen County, Indiana, National Technical Information Service PB 235 526, March 1974.*

Table 14

ANNUAL COSTS AND INSTALLATION COSTS AND ESTIMATED EFFECTIVENESS OF EROSION CONTROL PRACTICES

Primary Practices	Cost in Dollars: Approximate Equivalent Annual Cost	Cost in Dollars: Installation	Approximate Soil Loss Reduction (percent)
Conservation Tillage[a]			
Zero Tillage	7.20/Acre	--	93
Plow/Plant	1.50/Acre	--	76
Strip Till	5.00/Acre	--	87
Spring Instead of Fall Plow[b]	0.10/Acre	--	5
Crop Rotation[c]	1.80/Acre	--	60-80
Contouring	2.40/Acre	--	50
Contour Stripcropping	5.50/Acre[k]	10.00/Acre	85
Cover Crops	1.00/Acre[d]	12.00/Acre	90
Pasture Establishment	18.80/Acre[e]	77.00/Acre	90
Pasture Management	20.00/Acre	--	Variable
Critical Area Protection	64.00/Acre[f]	450.00/Acre	Variable
Gradient Terracing[g]	24.00/Acre	300.00/Acre	60
Bench Terracing[h]	50.00/Acre	625.00/Acre	90
Grassed Waterways[i]	0.10/Foot[j]	1.00/Foot	Variable
Diversions and Dikes	0.10/Foot[j]	1.25/Foot	Variable
Water and Grade Control Structures	200.00/Unit Average[j]	2,500/Unit Average	Variable
Wind Shelterbelts	6.50/Acre[d]	80.00/Acre	Variable
Streambank Protection	2.80/Foot[j]	3.50/Foot	Variable
Woodland Management	20.00/Acre	--	Variable
Farm Ponds	320.00/Unit[j]	1,500.00-5,000.00/Unit 4,000.00/Unit Average	Variable

Primary Practices	Cost in Dollars: Approximate Equivalent Annual Cost	Cost in Dollars: Installation	Approximate Soil Loss Reduction (percent)
Tiling	0.06/Foot[j]	0.70/Foot	These practices, although applied in the Region for purposes of soil productivity, are assumed to be of minimal value for the reduction of soil loss to lakes and streams
Tree Planting	8.00/Acre[j]	100.00/Acre	
Surface Drains	0.05/Foot[j]	0.60/Foot	
Deep Ditches	0.20/Foot[j]	2.25/Foot	
Wildlife Habitat	2.00/Acre[j]	25.00/Acre	
Liming	4.90/Acre[e]	20.00/Acre	
Mulching (for moisture)	60.00/Acre	--	

[a] *Costs vary widely due to the many different systems.*

[b] *Assumed cost for inconvenience.*

[c] *Excludes pasture or hayland establishment if required.*

[d] *Based on cost amortized over 30 years at 7 percent interest plus 0.10/acre, for inconvenience.*

[e] *Based on cost amortized over five years at 7 percent interest.*

[f] *Based on cost amortized over 10 years at 7 percent interest.*

[g] *Based on 420 feet of terrace per acre at 0.70/lineal foot amortized over 30 years at 7 percent interest.*

[h] *Based on 420 feet of terrace per acre at 1.50/lineal foot amortized over 30 years at 7 percent interest.*

[i] *Constructed without tile, tiling below waterway will increase cost to $1.70/foot.*

[j] *Based on cost amortized over 30 years at 7 percent interest.*

[k] *In addition to the amortized installation cost, this annual cost reflects other factors associated with contour stripcropping, inclusive of inconvenience, differences in fuel use, and differences in yield due to point rows and rotation crops.*

Source: Stanley Consultants, U.S.D.A. Agricultural Stabilization and Conservation Service, U. S. Soil Conservation Service, and SEWRPC.

practice. The cost of reducing loadings on surface waters from the practice must also involve considerations of the sediment delivery ratio. The universal soil loss equation can be used to predict soil loss reduction. For a given soil type, slope, length of slope, and location, a value can be obtained which would indicate the soil loss that might be expected from a bare field (fallow) over time. The cropping management factors and conservation practice factors then become the variables which determine the soil loss that might be expected from other conditions of surface cover, slope, and length of slope, Table 15 summarizes the cost-effectiveness for the various cropping management factors and conservation practice factors used in Tables 10 and 11.

The cost per ton of soil loss reduction is calculated using the soil loss expected from continuous corn planted up and down the slope in the fall with residue removed. This expected soil loss is primarily a function of soil type and slope. Costs generally increase with increased reduction and costs per ton of soil loss reduction generally decrease as the initial expected soil loss increases. Many methods do not reduce erosion to the allowable soil loss limit.

The cost and cost-effectiveness information provided in this chapter can be used to predict the relative cost of one practice versus another and the resulting reduction in potential erosion. There is no direct connection between erosion reduction and sediment delivery to the Region's surface waters. The sediment delivery ratio can be used to obtain approximate values, but this ratio may vary with initial soil loss as well as cropping management and conservation practice factors. The amount of other constituents retained on the land by using adequate soil conservation practices, such as nutrients and fertilizers, is difficult to quantify, but reductions will generally occur.

Table 15

COST EFFECTIVENESS OF EROSION CONTROL PRACTICES

System	Soil Loss Reduction (percent)	Estimated Soil Loss[a,c] Tons/Acre/Year			Cost/Acre[b] for Conservation Practice	Cost per Ton[a,d] Soil Loss Reduction		
		Example 1	Example 2	Example 3		Example 1	Example 2	Example 3
Fallow Ground	0	25.00	50.00	75.00	--	--	--	--
Fall Plowed Corn RdR	54	11.50	23.00	34.50	0.00	--	--	--
Spring Plowed Corn RdR	56	11.00	22.00	33.00	0.10	0.20	0.10	0.07
Spring Plow/Plant Corn RdR	76	6.00	12.00	18.00	1.50	0.27	0.14	0.09
Spring Strip Till Corn	87	3.25	6.50	9.75	5.00	0.61	0.30	0.20
Spring Zero Tillage	93	1.75	3.50	5.25	7.20	0.74	0.37	0.25
Spring Plow on Contour	78	5.50	11.00	16.50	2.40	0.40	0.20	0.13
Spring Plow Contour Strip	88	3.00	6.00	9.00	5.50	0.65	0.32	0.22
Spring Plow with Gradient Terrace[e]	74	6.50	13.00	19.50	24.00	4.80	2.40	1.60
Spring Plow with Bench Terraces[e]	96	1.00	2.00	3.00	50.00	4.76	2.38	1.59
Spring Plow Gradient Terrace-Minimum Till	98	0.50	1.00	1.50	29.00	2.64	1.32	0.88
Pasture Establishment[f]	98	0.50	1.00	1.50	18.80	1.71	0.85	0.57

[a]*The three samples given under each of the two designated columns are presented to depict a range of values which would be associated with the various soil types. Note that the soil loss estimates shown for Fall Plowed Corn RdR are comparable to the first value under each soil type in the last column of Table 10.*

[b]*Even though planting corn reduces erosion, a value of 0 is assigned to Fall Plowed Corn RdR and cost effectiveness is compared to this value.*

[c]*Fallow ground values of 25, 50, and 75 Ton/Acre/Year represent values common for soils in the Region.*

[d]*As compared to Fall Plowed Corn RdR system, vaules computed for initial conditions of 25, 50, and 75 Ton/Acre/Year soil loss from fallow ground.*

[e]*Terraces assumed to be used on slopes over 6 percent allowing corn planting where it may have been impractical.*

[f]*Establishment costs amortized over 10 years at 7 percent. Costs include management at $20.00/acre.*

Source: Stanley Consultants.

Chapter IV

METHODS TO CONTROL AGRICULTURAL CHEMICALS

INTRODUCTION

A wide variety of chemicals is used in agricultural operations in southeastern Wisconsin. Use of chemicals in woodland and forest management is limited. Many of the chemicals used are strongly adsorbed on soil surfaces, and methods to control erosion and sediment delivery outlined in Chapter III will be effective in preventing their movement to surface and ground waters. Other chemicals are soluble in water and are free to move with water movement over and through the soil and can adversely affect surface and ground water quality. The controls applicable to this type of chemical movement are controls that limit the application (amount, time, placement) of required chemicals, use different chemicals, or revise cropping systems to better use a given chemical to minimize potential pollutants from entering waterways.

PESTICIDE CONTROLS

Usage of pesticides and, more so, of herbicide, has increased during the last three decades and is still rising. Contacts were made with agricultural extension service personnel to determine which pesticides are commonly used in southeastern Wisconsin. Table 16 contains a list of these pesticides by crop. Also included in the table are chemical class, predominant transport mode, and approximate persistence in soil.

More pesticides can be lost in runoff water than in the sediment, even when pesticides concentration is higher in the latter. This is true because the amount of runoff water is greater than the amount of sediment transported. Pesticide residues dissolved in runoff water are also more difficult to control and move greater distances in

Table 16

PESTICIDES COMMONLY USED IN THE SOUTHEASTERN WISCONSIN REGION AND THEIR CHARACTERISTICS

Crop	Pesticide[a] Commercial Name	Chemical Class[b]	Predominant Transport Mode[c]	Approximate Persistence in Soil (days)
Corn	Atrazine (H)	TZ	SW	300-500
	Bladex (H)	TZ	SW	--
	Lasso (H)	AM	SW	40-70
	2, 4-D (H)	PO	W(amine and acid) S(ester)	
	Ferbam (I)			
	Furadan (I)	CB	W	--
Soybeans	Lasso (H)	AM	SW	40-70
	Amiben (H)	AR	W	40-60
	Treflan (H)	NA	S	120-180
	Lorox (H)	VR	S	120
Potatoes	Sevin (I)	CB	S	--
	Lannate (I)	CB	U	--
	Di-Syston (I)	OP	S	--
	Thimet (I)	OP	SW	--
Cabbage	Diazinon (I)	OP	SW	--
Onions	Diazinon (I)	OP	SW	--
	Parathion (I)	OP	S	--

[a] *(H) Herbicide (I) Insecticide.*

[b] *TZ, Triazines and Triazoles; AM, Amides and Anilides; CB, Carbamates and Thiocarbamates; PO, Phenoxy Compounds; AR, Aromatic Acids and Esters; NA, Nitroanilines; OP, Organophosphorus Compounds; UR, Ureas.*

[c] *Where movement in runoff from treated fields occurs, SW denotes those that will move in appreciable proportion with sediment and water; W, move primarily with water; S, move primarily with sediment; U indicates predominant mode of transport is unknown.*

Source: Stanley Consultants.

surface water than those adsorbed on sediments. Pesticides moving on sediment are adsorbed primarily on organic soil colloids. These colloids remain in suspension longer than the larger soil particles. Because of these modes of transport, practices that control runoff and reduce erosion also reduce loss of applied pesticides. However, other measures can be used in conjunction with these practices.

The solubility and adsorption characteristics and biodegradability of a pesticide affect its potential hazard as a groundwater contaminant. For example, an extremely toxic pesticide may not reach the groundwater because its chemical composition is unstable; it is rapidly biodegradable; or it has a low solubility.

The five classes of pesticides — organic botanicals, organic phosphates, carbamates, chlorinated hydrocarbons (CH), and organometallic compounds — have different properties which affect their potential for groundwater contamination.

Organic botanical pesticides are derived from plant matter. The plant origin of these chemicals makes their toxicity to both plants and warm-blooded animals quite low. These pesticides have limited use in agriculture because of the high cost, specific action, and tendency to deteriorate in storage.

Organic phosphates are easily and readily broken down in the soil. These substances are generally degraded to lesser compounds (some of which may be toxic) in less than three to six months by sunlight, soil bacteria, and water.[1]

Carbamates containing nitrogen also break down in the soil in a relatively short time. The resultant metabolic products are nontoxic.

Chlorinated hydrocarbons are relatively stable pesticides. They produce long-lasting toxic residues that are stable in a wide variety of environmental conditions. Studies indicate that soils with high organic content retain more chlorinated hydrocarbon residue than sandy or mineral soils. Due to adsorption processes in the soil, chlorinated hydrocarbons do not generally infiltrate into the subsoil.

Organometallic pesticides contain metallic elements in their structure. The metallic elements in these pesticides are generally water insoluble; also they have no adverse effect on groundwater. However, in some cases the metallic element persists in the soils and interferes with plant growth.

[1] *B. A. Stewart et al, Control of Water Pollution from Cropland, Volume 1, A Manual for Guideline Development, Office of Research and Development, Environmental Protection Agency, EPA 600/2-75-026a, February 1975.*

Pesticide Placement

Herbicide or insecticide placement in or on the soil can affect the potential for contamination of runoff. The best way to minimize this hazard is to place the pesticide in a narrow band below the soil surface. Conversely, broadcast applications on the surface are more likely to create a problem. Incorporation into the soil may be practical for pesticides such as volatile or photosensitive herbicides, but impractical for others. Another measure is the use of narrow rather than wide band applications. If herbicides are placed in narrow bands over the planted row, a supplemental cultivation is needed to control weeds between the treated bands. Bands should be wide enough to prevent weeds from competing with the crop and permit cultivation to the edge of the band without injuring the crop. Subsurface sweep applicators place the band precisely but require increased power. However, this method can cut herbicide requirements by as much as 50 percent. Unfortunately, fuel shortages can restrict this method and, as in the case of soybeans, farmers may use broadcast applications of herbicides. Broadcast applications are also the only feasible treatment in close-rowed crops. The heavy surface mulches which are characteristic of certain conservation cropping systems may complicate pesticide placement.

Pesticide application for above-ground insects should always be based on plant damage or actual pest counts, and be used only where potential economic losses justify it. On large scales, only infected areas should be treated. Pesticides are often applied as a preventive measure for soil insects. Unfortunately, this may be the only safe policy because methods to predict populations that will cause economic damage have not been developed. Whenever possible, cultural or biological controls should be used where predictive techniques have not been developed. A similar situation exists for weed control. Specific problems should be identified and specific controls used.

Spraying applications should be done when the air is still and the potential for drift is reduced, generally in the early morning or evening. During windy conditions, temperature inversions, and when heavy rain is predicted, spraying should be delayed.

Unfortunately, pesticides are generally applied in early spring when high rainfall and accompanying high runoff and sediment transport can occur. Because pesticide losses in runoff are relatively great only when rainfall occurs shortly after application, the ideal situation is to move pesticide treatment away from peak runoff periods, yet maintain the pesticide effectiveness. This situation makes post-emergent treatments preferable to pre-emergent treatments. However, post-emergent treatments have nonenvironmental disadvantages in that they allow early competition of weeds with crops, require labor at a critical time on many farms, often are not as effective as pre-emergent treatments, and allow no later options as do pre-emergent applications, if weather interferes with the treatment. The timing of pre-plant soil incorporated chemicals is not so critical as that of pre-emergent types. Insecticides that are equally effective whether applied in early spring or in late spring should be applied as late as possible because the runoff hazard is less and shorter-lived chemicals can be used more effectively.

Aerial placement of pesticides increases the likelihood of uneven distribution of pesticides on the crop and increases spray volatilization and drift which can injure susceptible crops growing nearby, and directly contaminate nearby surface waters. Because a smaller amount of the chemical reaches the target, a higher rate may be needed to obtain the same degree of pest control. The drift hazard can be reduced by spraying only during periods of low wind and when the wind is blowing away from susceptible crops. For public health reasons, spraying should not occur during temperature inversions when dispersion rates are suppressed. Special pesticide formulation, special nozzles, and/or low pressures can be used to reduce the possibility of contaminating adjacent areas. Aerial spraying eliminates wheel track compaction than can reduce crop yields and may be the only effective means to combat sudden wide-spread pest infestations.

Alternative Pesticide Controls

If more than one chemical of comparable price and effectiveness is available as a specific control, the compounds least likely to cause water pollution should be used. Preference should be given to pesticides with low toxicity, that are not persistent, and do not build up through the food chains. In an area with appreciable runoff and little erosion, pesticides that move primarily with sediment should be favored over those that move or dissolve more easily in water. Using different chemicals to obtain the same control in successive years prevents the build-up of resistance in the target species and results in lower residue levels of those compounds that are relatively stable.

The formulation of a pesticide can affect runoff contamination potential. If surfactants or nonphytotoxic petroleum on linseed oils are added to the spray mix of foliar-applied herbicides, the penetration and translocation of the chemicals within the plant can be increased. Different formulations with the same active ingredient may present different pollution hazards because of other components in the pesticide formulation. Solvents, additives, or dilutants may be more toxic to fish and other aquatic organisms than the herbicide itself. Controlled-release products and foams may increase the effectiveness and reduce treatment rates in the future, but are currently experimental. Granular pesticides, especially if incorporated into the soil, are environmentally preferable to liquids because application losses are lower.

Mechanical weed control includes hand-pulling, mowing or cutting, and burning, but the most common method is tillage. Pre-plant tillage not only controls weeds, but prepares the seedbed. However, tillage has many drawbacks. Erosion may be increased, soil structure may be harmed, and the economics are unfavorable.

Although biological controls have resolved a substantial number of pest problems, these methods have not currently proven to be entirely reliable. Biological methods appear to be most effective against pest populations that had been reduced by preliminary treatment with insecticides. Other problems with this type of control are the selectivity of parasites on the biological agents and the fact that insects cannot be introduced to control all types of plants. Insect sterilization is one of the most selective and environmentally acceptable means of suppressing insect populations. Insect toxins and pathogens can also be used for control. Heliothic virus was registered for control of bollworm on cotton. One insect pathogen, Bacillus thuringiensis, is now commercially produced. Insect attractants are another aid to insect control. Lights and other traps are used to reduce the need for scheduled spraying.

Cropping Practices

Crop rotations can be used in some instances to suppress populations of insects, weeds, or plant disease organisms, permitting the use of less chemical pesticide and reducing soil erosion. For example, crop rotation can control root worms in corn.

Using resistant crop varieties reduces the need for chemical treatment. Resistant varieties have proven to be a practical means to suppress disease and insect pests in crops including corn, soybeans, alfalfa, wheat, and oats. For example, certain soybean varieties are resistant to phythophthora (root rot). Certain oat varieties are resistant to crown rust and certain alfalfa varieties resist bacterial wilt. Seed cost of resistant varieties is not significantly higher than for the seed cost of more susceptible varieties. Crop resistance may be insufficient in itself, but can reduce the need for chemical treatments.

Recommended planting times for many crops can span a several week period. However, for certain insects, the exact time of planting within this period can affect infestation and thus affect the eventual need for insecticides. Early planting of corn can help reduce infestation by the European corn borer. Hybrid corn varieties are resistant to first generation borers which lay their eggs in early planted fields. However, eggs of second and third generation borers which must be controlled by insecticides are usually laid in late planted fields. Early planted corn is also less affected by the corn ear worm in northern states.

In continuous minimum tillage systems, planting between last year's rows helps reduce populations of soil insects, and the need for heavy insecticide applications is reduced. Disadvantages are the difficulty of planting in the area compacted by the wheels of equipment used the previous year, and the loss of fertilizer placed in the row of the crop during the preceding year for use by the new planting.

Integrated Control Programs

An effective integrated control program is defined as any combination of chemical, biological, cultural, or mechanical control techniques used to eradicate the pests or to decrease their population to acceptable damage levels and maintain it there. The development of an integrated control program is a complex task that requires a wide-ranging knowledge of the many topics pertaining to crop production and to pest control.

Other Considerations
Whenever chemicals are handled or used, certain "common sense" practices should be followed.

1. Pesticides should always be used in accordance with instructions on the label.

2. Chemicals should be stored to minimize the hazard of possible leakage.

3. Empty containers should be disposed of in accordance with procedures in the Federal Environmental Pesticide Control Act of 1972 (Public Law No. 92-516). Containers should be rinsed three times and punctured before burying. When possible, the rinse water should be added to the spray tank. If this is not possible, the rinse water should be treated as excess pesticide and buried with the container.

FERTILIZER CONTROLS

Chemical fertilizers have been used for many years to supplement soil-supplied nutrients to produce optimum crop yields, improve plant quality, and reduce erosion by increasing vegetative cover. Nitrogen, phosphorus, and potassium are the three plant nutrients most commonly applied in chemical fertilizers. Many other chemicals are contained in fertilizers, but at present there is no indication that these other chemicals pose any significant pollution problems either because they are already common in the environment or because they do not stimulate any unpredicted or undesirable growth in aquatic biological systems. Factors influencing nutrient losses are precipitation and other sources of water such as irrigation, temperature, soil, kind of crop, nutrient release through mineralization, and denitrification. A brief review of the movement of fertilizer solids within the soil helps provide an understanding of the pollution prevention and control measures dealing with fertilizers. Nitrogen and, to a lesser extent, potassium are soluble and move from their zone of placement in the soil. This movement is largely vertical (up or down) depending upon the direction of water movement. Nitrates can be leached below the root zone of sandy soils during periods of precipitation and move downward in the soil profile in heavier textured soils during cooler periods of low evapotranspiration. Nitrogen fertilizers usually contain one or more of four nitrogen forms: nitrates, ammonia, ammonium, or urea. Each form has specific characteristics which determine the conditions or uses for which it is best suited.

Nitrates (NO_3) "dissolve" in water and, therefore, move in the soil with movement of soil water. The nitrate form of fertilizer is not suited for fall application on any soil or early spring application on sandy soils because of the likelihood of leaching. This form is also not suitable for soils that are often very wet in April and May because of possible loss by denitrification under the anaerobic conditions of the wet soils.

Nitrates are constituents of natural soils and of fertilizers that represent a potential groundwater pollution problem. Nitrates are commonly found in low concentrations in nonpolluted groundwater. Leachates from highly fertile unfertilized agricultural land may have a higher content of nitrates reaching groundwater than leachates from nearby fertilized well-managed cropland low in natural fertility.[2] A study in southwestern Wisconsin[3] showed little evidence that fertilizer nutrients pollute groundwater. After two years of collecting water samples from streams during low-flow periods (representing outflow of groundwater), data indicated plant nutrients are a relatively unimportant source of groundwater pollution. However, nitrates could become a future problem if excessive nitrogen is added on some soils. They also can become a problem if short-circuiting between the nitrogen source and groundwater aquifer occurs.

Ammonia (NH_3) is a gas at atmospheric pressure but can be compressed into a liquid, anhydrous ammonia. When applied as anhydrous, the ammonia reacts with water in the soil and changes to the ammonium form (NH_4^+). Ammonia in water exists in equilibrium as the ammonium ion according to the following expression: $NH_4^+ = NH_3^+ + H^+$. The ammonia form, NH_3, escapes as a gas. For this reason, it must be injected under the soil surface. Although water soluble, ammonium attaches to clay and organic matter particles which prevents leaching. During the growing season, soil microorganisms convert the ammonium to nitrate which is the main form taken up by plants. The ammonium form is taken up by certain cereal crops and other grasses. Soil conditions most favorable to this conversion process include a soil pH of 7, moisture of 50 percent of the soil's water-holding capacity, and soil temperatures of 80° F. Unfavorable conditions are a pH below 5.5, a waterlogged condition, and temperature under 40° F. The conversion process is a function of soil acidity, availability of free oxygen, and ammonia gas exchange which is influenced by temperature. Anhydrous ammonia has a slight advantage for fall application due to these factors.

Urea $(COCNH_2)_2$ undergoes a three-step change before it is used by crops. Enzymes in the soil or plant residue convert urea N to ammonia N. The ammonia reacts with soil water to form ammonium N, and microorganisms convert it to nitrate. Conversion to ammonia occurs in two to four days if soil temperatures and moisture conditions are favorable for plant growth. Lower temperatures slow the process, but it will continue until freezing. Leaching losses are seldom a problem under field conditions. Some of the ammonia formed from urea applied on the surface will be volatilized. The greatest volatilization loss can be expected when the soil pH is above 7, the soil temperature is high, and soil moisture is low. Table 17 shows the suitable characteristics and method of application of commonly used nitrogen fertilizers.

---

[2] *T. L. Willrich et al, "Agricultural Practices and Water Quality" in Proceeding of a Conference Concerning the Role of Agriculture in Clean Water, November 1969, Iowa State University, Ames, Iowa, November 1970.*

[3] *Ibid.*

Table 17

CHARACTERISTICS AND SUITABILITY OF COMMONLY USED NITROGEN FERTILIZERS

Fertilizer Material	Percent Nitrogen	Form of Nitrogen in Fertilizer	Suitable For: Fall Plow-Down for Corn	Spring Pre-Plant	Side-[a] dressing Corn	Top-dressing[b] Small Grains and Grasses
Dry (Solid) Forms						
Ammonium Nitrate	33.5	1/2 Ammonium 1/2 Nitrate	Not Suitable	Good	Excellent	Excellent
Ammonium Sulfate	20.5	Ammonium	Excellent	Excellent	Excellent	Good
Calcium Nitrate	15.5	Nitrate	Not Suitable	Good	Excellent	Excellent
Cal-nitro (ammonium .... nitrate + limestone)	26.0 26.0	1/2 Ammonium 1/2 Nitrate	Not Suitable Not Suitable	Good Good	Excellent Excellent	Excellent
Diammonium Phosphate	18.0	Ammonium	Excellent	Excellent	Excellent	Excellent
Urea	45.0	Ammonium-forming	Excellent	Excellent	Excellent	Good-winter Poor-summer
Liquid Forms						
Anhydrous Ammonia[c] (liquid under pressure)	82.0	Ammonium-forming	Excellent	Good	Excellent	Unadapted
Aqua Ammonia[c] (anhydrous ammonia + water)	20.0-24.6	Ammonium-forming	Excellent	Good	Excellent	Unadapted
Low-Pressure N Solutions[c] (ammonium nitrate-urea-ammonia-water)	37.0-41.0	2/3 Ammonia[d] 1/4 - 1/3 Nitrate	Poor Poor	Good Good	Excellent Excellent	Unadapted Unadapted
Nonpressure N Solutions (urea-ammonium nitrate-water or UAN)	28.0-32.0	1/4 Nitrate[d] 3/4 Ammonium	Poor	Excellent	Excellent	Excellent-spring Poor-summer

[a]*Placing fertilizer below the soil surface between the rows of a row crop.*

[b]*Spreading fertilizer on the soil surface.*

[c]*Must be injected into the ground when applied to avoid N loss to the air as gas.*

[d]*Approximate proportions.*

Source: Adapted from C.D. Spier, Types and Uses of Nitrogen Fertilizer for Crop Production, Agronomy Guide, Cooperative Extension Service, Purdue University, West Lafayette, Indiana, 1974.

While some soluble phosphorus compounds move in runoff (see Chapter 2), phosphorus generally attaches to soil particles and moves primarily by erosion. Total P content of soils ranges from 0.01 to 0.13 percent.[4] Phosphorus content of surface soils reflects fertilizer applications and farm management while that of subsoil reflects geologic conditions.

Nutrients may be applied singly or in combinations. A farmer may purchase a mixed or blended fertilizer that contains more of one nutrient than is needed because it is cheaper or the desired ratio of nutrients is unavailable. Using such mixes and blends can lead to a certain degree of overfertilization. Since the amounts of N required usually predominate, the excess nutrients are generally P and K. Because nutrients are moved from agricultural land by leaching, direct runoff, and association with sediment from erosion, reducing nutrient losses from agricultural operations can be accomplished by the following three general approaches:

[4]*B. A. Stewart et al, Control of Water Pollution from Cropland, Volume 1, A Manual for Guideline Development, February 1975.*

1. Determination of the proper amount, form, method, and time of nutrient application and placement to ensure efficient use by plants.
2. Use of cultural practices, including tillage and crop rotations that minimize nutrient losses.
3. Reduction of soil erosion and surface water runoff by conservation measures.

Fertilizer Placement

Fertilizer effectiveness can be increased by using the proper method of application and placement in relation to root depth and moisture. Increased plant use reduces excess nutrients, ultimately reducing potential pollutants. Placement of phosphate fertilizers with respect to the plant root system is important because of its limited movement. On soils of low or moderate fixing capacities, broadcasting fertilizers may be the most economical method of application, but nutrients may be lost if the fertilizer is not incorporated by plowing, disking, etc.

Many environmental factors such as weather, pests, etc., influence potential crop yields and the amount of plant nutrients released by the soil for plant uptake, but soil tests and plant analysis are two methods of determining crop needs. A soil test made prior to fertilizer application should be used to determine the various amounts of plant nutrients required to produce a specific yield. Application rates should not be based on crop requirements alone. Overfertilization could cause excess nutrient losses. A sample should be taken every four years and proper sampling techniques used to obtain accurate soil fertility information. Soil tests are generally performed for pH (soil acidity), P_1 (available phosphorus), P_2 (reserve phosphorus) and K (potassium). Agronomists have generally not approved of any nitrogen tests. Crop nitrogen requirement recommendations can be made considering soil pH, organic matter content, previous crop, amount of nitrogen previously applied, and desired yields. In some instances, soil testing for secondary or micronutrients may be warranted to diagnose symptoms of abnormal growth or identify nutrient deficiencies before they appear. However, micronutrients do not generally pose a threat to water quality. Another guide for fertilizer use is plant analysis. Plant analysis measures total nutrient uptake and determines nutrient status. Samples taken throughout the growing season indicate whether the nutrients are adequate. This information can be used to adjust fertilizer applications rates and timing or adjust cultural practices. Crop residue left on the fields should also be considered. Table 18 contains a nutrient content of crops commonly grown in southeastern Wisconsin. Potential yields, soil tests, and plant analysis, soil and residue nutrient supplies, and fertilizer efficiency can be used to estimate an adequate fertilization level.

Proper timing of nitrogen applications will maximize the efficiency of utilization by crops, thereby reducing the pollution hazard. Nitrogen may be fall or spring applied for fall-sown green crops. Row crop nitrogen can be applied at planting time, the remainder can be side-dressed depending on soil, climatic, and crop conditions. The form of nitrogen should be considered in conjunction with time of application. Phosphorus and potash fertilizer should be applied at seeding time or earlier.

Side-dressing corn with nitrate fertilizer about three to four weeks after emergence is known as summer side-dressing. When applied at this time, nitrogen is usually injected as ammonia gas. This method reduces the possibility of runoff, and rapid use by the actively growing plant reduces the potential for leaching. Disadvantages of this method are the need for sufficient rainfall to move the nitrogen into the root zone and conversely the problem that wet periods can delay application, resulting in decreased yields.

Fall fertilization sometimes is convenient. This practice uses farm labor during a time when it is more available. However, leaching from fall-applied ammonia nitrogen may be in excess of 10 percent, which constitutes a potential nitrate leaching hazard. This threat may be reduced by the potential denitrification which probably occurs during winter conditions.

Alternative Fertilizers

Animal wastes can provide a slow release source of nitrogen which makes less nitrate available at any one time for leaching. This property also can be a disadvantage in that nitrogen release can continue during fall and winter months after the crop is harvested although this release may be minor under winter soil temperatures. Application of animal wastes is discussed in more detail in Chapter 5. Wastes from man in the form of sewage sludge are finding wide use throughout the Midwest. Waste lime sludge from water treatment plants also can be used on soil. Application of these materials to agricultural land is discussed in Volume Two of this report.

Legumes can supply appreciable amounts of nitrogen to the soil. The values range from about 80 pounds per acre per year for red clover to 200 pounds per acre per year for alfalfa. Some of the nitrogen can be lost as a legume decomposes. Plowing such plants into the soil provides a natural fertilizer.

Cropping Practices

Using rotations which include crops requiring little or no nitrogen fertilizer (soybeans and legumes) and crops requiring large amounts can reduce the long-term average amount of nitrogen available for leaching. Including deep-rooted crops such as grasses and legumes can also reduce nitrate leaching because these plants utilize nitrates from depths below the normal rooting zone of most other crops.

Winter cover crops can reduce nitrate leaching by extracting soil water during fall and spring so that less water is available for leaching and by utilizing the nitrate remaining from the preceding crops. Wind and water erosion also is reduced.

COST EFFECTIVENESS OF AGRICULTURAL CHEMICAL CONTROLS

Controlling soil erosion will reduce the delivery of many agricultural chemicals to surface waters. Soil erosion control costs are reviewed in Chapter 3. Most of the other potential controls described in this section involve changes in practices to minimize the effects of agricultural chemicals on surface and ground waters for which the major cost would be in educating users with methods available. Some systems, such as using fertilizer tests, can result in decreased cost. Others, such as switching pesticides, may increase cost.

Table 18

ESTIMATED N AND P PROVIDED BY CROP RESIDUES

Crop	Yield/Acre	Nitrogen pounds/acre	Phosphorus pounds/acre
Corn (stover)	4.5 tons	100	16
Soybeans (straw)	1.0 ton	25	4
Oats (straw)	2.0 tons	25	8
Potatoes (vine)	1.0 ton	90	8
Cabbage	20.0 tons	150	16
Onions	7.5 tons	45	8
Alfalfa	4.0 tons	200	18

Source: Adapted from B. A. Stewart, Control of Water Pollution from Cropland, February 1975.

(This page intentionally left blank)

Chapter V

METHODS TO CONTROL ANIMAL WASTES

INTRODUCTION

Animal wastes are a potential source of water quality degradation. Release of livestock and poultry manure into the environment is an inevitable result of animal husbandry. Historically, animal manure was deposited randomly on the earth surface where the nutrients were utilized by growing vegetation and the organic matter was incorporated into the soil. Although this practice continues, many farm animals are raised and managed in confined operations. The result of these confined operations is an accumulation of wastes in localized areas. Animal waste constituents of pastureland and barnyard runoff, animal waste on pastureland and in barnyards, feedlots, and manure piles can contaminate water by surface runoff, infiltration, and volatilization. Groundwater under feedlots frequently contains nitrates, ammonia, and organic carbon. Atmospheric ammonia measured near feedlots can be as much as 20 to 30 times greater than near control sites.[1] Stewart, et al,[2] found that nitrate concentrations under feedlots varied from 0 to 5,137 pounds per acre in a 20 foot profile. The data indicate that localized pollution of the water table aquifer with nitrogen can be expected near and under animal feedlots. However, since the acreage used for feedlots is limited, widespread groundwater pollution due to infiltration from these areas is unlikely. Dispersion may lower concentrations, but water supply wells in the vicinity of the feedlot should be monitored to avoid health problems in man or animals using the water supply.

Holding ponds, settling basins, and lagoons are often used to store manure and must be designed considering the hydrologic, chemical, physical, and aesthetic factors of their performance. Lining lagoons can prevent potential seepage from them.

Pollution of groundwater from field spread manure is generally not a problem. This is particularly true for the relatively small operations found in southeastern Wisconsin.

Existing data on the quality of runoff from cattle feedlots indicate a highly variable quality depending on rainfall intensity, temperature, feedlot surface, moisture content, and manure accumulation. Miner[3] showed that the feedlot runoff is a source of high bacterial concentrations and that the greatest pollutant concentrations were obtained during warm weather, during periods of low rainfall intensity, and when the manure had been made soluble by water soaking. In the runoff from these studies, ammonia nitrogen ranged from 16 to 150 mg/l, suspended solids from 1,500 to 12,000 mg/l, and COD from 3,000 tc 11,000 mg/l. Average chloride and phosphate concentrations were 300 and 50 mg/l, respectively, for lots with concrete surfaces.

Ammonia may be released into the air from feedlot storage tanks, treatment facilities, and other manured surfaces. A study by Hutchison and Viets[4] showed significantly higher rates of ammonia adsorption near feedlots as compared with samples collected in other rural areas. They found that a water surface could absorb up to 200 pounds of ammonia per acre annually.

Alternative control methods to prevent potential pollutants from reaching surface or ground water from animal production facilities are described in this chapter.

ANIMAL WASTE CONTROL CONSIDERATIONS

The great potential for water pollution from concentrated animal facilities requires a high level of waste management. Several control and treatment methods are available to reduce pollution from animal wastes. Control of water pollution from livestock raised on pasture generally is accomplished by management practices rather than by using wastewater treatment systems. These methods will be discussed later. Conversely, several control and treatment methods are available for reducing pollution from animal wastes in confined feeding facilities.

The number and variety of methods available to handle wastes from confined feedlots suggest an initial screening to select those appropriate for use in southeastern Wisconsin. These methods may be subdivided into two categories:

1. In-process technology.

2. End-of-process technology.

In-process technology refers to the physical and operational characteristics of the feedlot and their potential impact

---

[1] *Methods for Identifying and Evaluating the Nature and Extent of Nonpoint Sources of Pollutants*, U. S. Environmental Protection Agency, EPA 430/9-73-014, October 1973.

[2] *T. L. Willrich et al, "Agricultural Practices and Water Quality," in Proceeding of a Conference Concerning the Role of Agriculture in Clean Water, November 1969, Iowa State University, Ames, Iowa, November 1970.*

[3] *J. Ronald Miner, "Agricultural Waste Management," Journal of the Environmental Engineering Division, Volume 100, American Society of Civil Engineers, April 1974.*

[4] *Ibid.*

on selection of waste management alternatives. Characteristics such as site selection, housekeeping, feed formulation, and water utilization are directly concerned with what is happening in the feedlot itself, although all have a direct effect on the quantity and characteristics of waste materials leaving the feedlot.

End-of-process technologies affect waste materials leaving the feedlot proper. Table 19 contains a list of end-of-process technologies available based on a recent state-of-the-art review of available alternatives.[5] Treatment technologies were analyzed to determine whether they apply to manure or runoff; whether they provide containment, complete treatment, or partial treatment; whether they are considered the best practicable control technology currently available (BPCTCA); the best available technology economically achieveable (BATEA) or experimental technology; and whether they are primarily a biochemical or physical-chemical process. The screening to select technologies appropriate to the study area is accomplished by:

1. Eliminating all experimental treatment technologies from Table 19 to assure the feasibility and reliability of any possible recommendations in subsequent planning activities.

2. Determining which of the remaining technologies are applicable, given the climate, soils, slopes, herd types, and sizes, and the prevailing management practices in Southeastern Wisconsin.

Experimental technologies in Table 19 were eliminated for such reasons as uncertainty of success, high cost, size of operations in the Region, and probable nonacceptance by potential users. Selection from the remaining alternatives was based on discussions with local Soil Conservation Service and Cooperative Extension Service personnel and field observations. The treatment technologies which were selected are: land utilization, runoff controls, and lagoons for treatment. The scope of this study includes discussion of the processes used in these systems, the effectiveness of the processes, and the cost of the processes, but does not develop specific control systems. These processes are more easily incorporated into new facilities than existing ones, but can be applied to both. The typical system would involve storm water diversions away from the feedlots, holding tanks for collected manure, and land application of the stored (and partially treated) manure.

FEEDLOT SITE SELECTION CONSIDERATIONS

Several considerations influence the selection of a confined animal feeding facility site. These considerations are: regulations and spatial requirements, topographic features, climate, soils and geology, and social considerations. Proper site selection can minimize potential contamination

[5] *U. S. Environmental Protection Agency, "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Feedlots Point Source Category," EPA 440/1-85-004-9, January 1974.*

Table 19

END-OF-PROCESS WASTE HANDLING ALTERNATIVES

	Application		Function			Status			Type of Process	
Treatment Technology	Manure	Runoff	Containment	Complete Treatment	Partial Treatment	BPCTCA	BATEA	Experimental	Bio-chemical	Physical Chemical
Land Utilization	X			X		X			X	
Compost and Sell	X			X		X			X	
Dehydration (Sell or Feed)	X			X		X (Sell)	X (Feed)			X
Conversion to Industrial Products	X			X				X		X
Aerobic SCP[a] Production	X			X				X	X	
Aerobic Yeast Production	X			X				X	X	
Anaerobic SCP[a] Production	X			X				X	X	
Feed Recycle	X			X				X		X
Oxidation Ditch (Spread or Feed)	X				X	X (Spread)	X (Feed)		X	
Activated Sludge	X				X		X		X	
Wastelage	X				X		X		X	
Anaerobic Fuel Gas	X				X			X	X	
Fly Larvae Production	X				X			X	X	
Biochemical Recycle	X				X			X	X	
Conversion to Oil	X				X			X		X
Gasification	X				X			X		X
Pyrolysis	X				X			X		X
Incineration	X				X			X		X
Hydrolysis	X				X			X		X
Chemical Extraction	X				X			X		X
Runoff Control		X	X			X				
BLWRS[b]		X		X				X	X	
Lagoons for Treatment		X			X	X			X	
Evaporation		X	X		X	X				X
Trickling Filters		X			X			X	X	
Spray Runoff		X			X			X	X	
Rotating Biological Contactor		X			X			X	X	
Water Hyacinths		X			X			X	X	
Algae		X			X			X	X	

[a] *Single Cell Protein.*

[b] *Barriered Landscape Water Renovation System.*

Source: R. G. Hoeft, D. R. Keeney, and L. M. Walski, "Nitrogen and Sulfur in Precipitation and Sulfur Dioxide in the Atmosphere in Wisconsin, Journal of Environmental Quality, Volume 1, No. 2, 1972.

of groundwater, obviate the need for storm drainage control, and minimize adverse odor effects from feedlots.

Regulations and Spatial Requirements

Spatial requirements for livestock feeding facilities vary with types of facility and climate in which they are located. Total area required for a system is composed of the production area, extraneous storm water runoff diversion ditches, storm water collection and retention structures, waste storage, treatment and ultimate disposal sites, and the buffer zone around feeding facilities and/or ultimate disposal sites. Space requirements for the various systems involved in proper treatment are summarized in Table 20.

In selecting a feedlot site, consideration must be given to the location of land available for the storage, treatment, or surface application of wastes produced.

Topographic Features

Both slope and natural drainage to surface water from a proposed site should be considered. Land which is too flat may be poorly drained. Poor drainage results in sloppy pen conditions and increased potential for groundwater contamination. Conversely, surface runoff is difficult to control from areas with extreme gradients. A site with 2 to 6 percent slopes generally eliminates the previously mentioned problems.

Runoff to surface waters is an important consideration. Although certain agencies have set minimum distances between feedlots and surface waters, the pollution potential is not necessarily reduced or eliminated by distance. Control of runoff is more important.

Other Siting Considerations

Climatic considerations include temperature, precipitation, evaporation, wind velocity and direction, and solar radiation. Wind affects the operation of a feeding facility in many ways. During the summer, wind can cause dusty pen conditions, and during the winter it can cause drifting snow. Adverse livestock comfort conditions can lead to reduced feed conversion efficiencies in cold weather. Prevailing wind direction is an important factor to consider in relation to potential sources of odor complaints.

Solar radiation affects both the production efficiencies of animals and the efficiency of waste management and pollution control facilities. Evaporation from a wet manure

Table 20

APPROXIMATE AVERAGE SPACE REQUIREMENTS FOR COMPONENTS OF LIVESTOCK CONFINED FEEDING OPERATIONS

Feeding Operation Components	Beef	Dairy	Reference
Paved Feedlot and Barnyard	30-60 feet^2/animal	75-100 feet^2/animal	E. G. Bruns and J. W. Crowley, "Solid Manure Handling for Livestock Housing, Feeding and Yard Facilities in Wisconsin," University of Wisconsin Extension, November 1972.
Unpaved Feedlot and Barnyard . . .	400 feet^2/animal	900 feet^2/animal	Ibid.
Storage-Liquid[a]	5 feet^3/1,000 pounds liveweight/day	6 feet^3/1,000 pounds liveweight/day	Livestock Waste Management with Pollution Control, Midwest Plan Service, Ames, Iowa, 1975.
Storage-Stacking[b]	1.3 feet^3/1,000 pounds liveweight/day	1.6 feet^3/1,000 pounds liveweight/day	Ibid.
Lagoon-Anaerobic	1,180 feet^3/1,000 pounds liveweight	1,150 feet^3/1,000 pounds liveweight	Ibid.
Lagoon-Aerobic	2,200 feet^3/1,000 pounds liveweight	2,500 feet^3/1,000 pounds liveweight	Ibid.
Land Spreading-Corn[c]	0.4 acre/animal/year	0.5 acre/animal/year	P. H. Jones, "Theory and Future Outlook of Animal Waste Treatment," in Proceedings Animal Waste Management, Cornell University, January 1969.
Land Spreading-Pasture[d]	0.1 acre/animal/year	0.2 acre/animal/year	Livestock Waste Management, 1975.

[a] *Includes flush and slurry water.*

[b] *Includes two to three pounds bedding for beef and six to eight pounds bedding for dairy cattle per 1,000 pounds liveweight per day.*

[c] *Represents maximum application of nitrogen which will not reduce corn yield or cause water pollution.*

[d] *Represents maximum application of nitrogen to avoid groundwater pollution problems.*

Source: Stanley Consultants.

surface is a function of humidity, air movement, and solar radiation. Solar radiation may only be controlled to a limited degree. Feedlots located on northern or eastern slopes receive less intense sunlight and correspondingly have maximum temperatures for shorter periods during the day than sites on southern or western slopes. Locating livestock facilities on northern and eastern slopes is desirable for summer conditions, but is less desirable for winter conditions since animals would require more shelter.

Within southeastern Wisconsin, precipitation is generally uniform over the seven counties. Thus precipitation as such does not affect the choice of a site.

Soils and underlying geology of the proposed site should be investigated to determine the potential of groundwater contamination. Highly permeable soils, shallow soils over fractured bedrock, and high water tables should be avoided.

ANIMAL WASTE CONTROL SYSTEMS

Whether the animal producer is constructing a new feedlot or incorporating pollution control measures into an existing feedlot, basic concepts of animal waste management are the same. They include:

1. Isolation of wastes from uncontaminated surface runoff.

2. Transport of wastes including collection and handling of liquid, solid, or slurry wastes.

3. Waste treatment, storage, or both.

4. Disposal or utilization of treated wastes.

Animal Production Systems

Production systems vary from pasture systems with little or no designed waste management to total confinement buildings with a high degree of waste treatment. Figure 10 shows the various types of animal production facilities. The livestock producers in the study area use a combination of confined and unconfined systems. This combination usually consists of pasture and of lot and shelter.

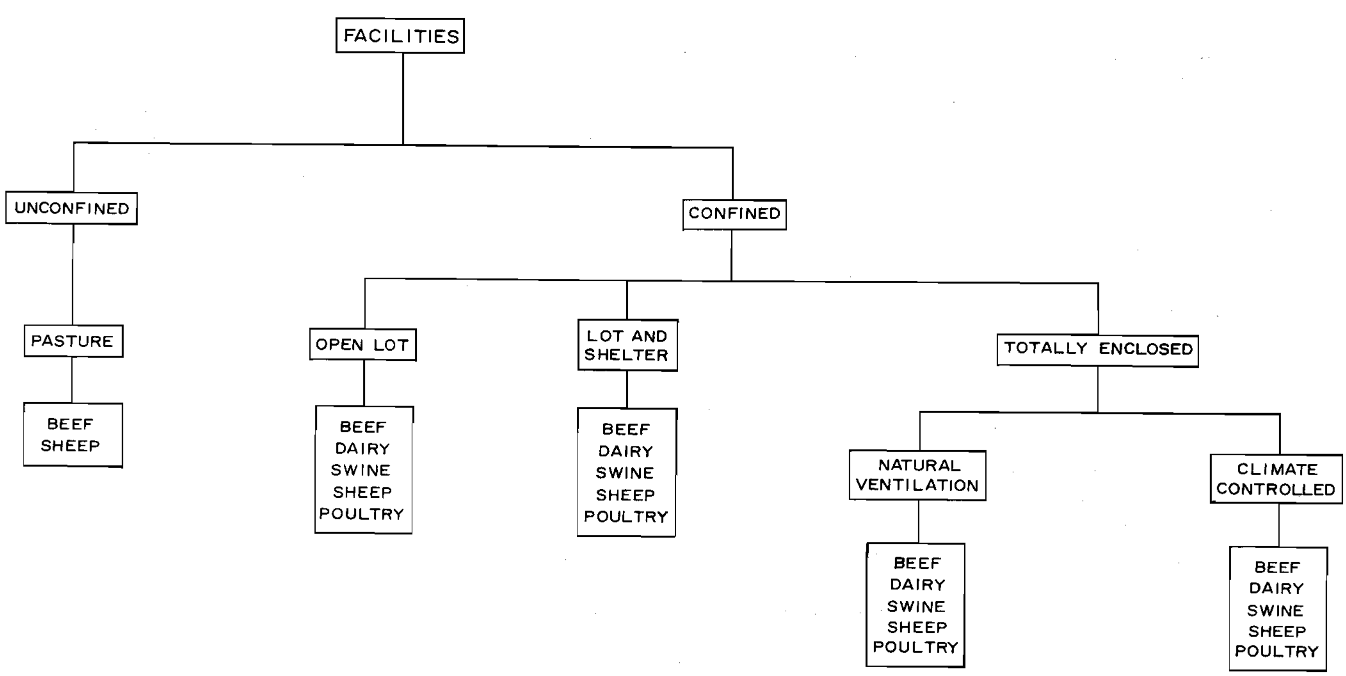
Waste Collection and Transport

Transport includes the collection and handling of wastes. Animal wastes may be collected and handled as solids (greater than 15 percent solids), liquids (0-4 percent solids), or slurries (4-15 percent solids). Dry systems minimize the volume of waste material that must be further processed while wet systems utilize the efficiency obtained with a liquid to transport wastes. The low cost of water and the efficiency of pumping systems can make liquid collection advantageous if utilization or disposal of the wastewater is possible.

In dry systems, manure is usually deposited on the floor of the pen, lot, or under the cage and collected and removed intermittently. Manure from an open feedlot may be stored for several months before being removed as compared to dairy operations which use mechanical equipment to remove waste from the building daily. Gutter cleaners, shuttle

Figure 10

POSSIBLE COMBINATION OF ANIMAL PRODUCTION FACILITIES



Source: Livestock Waste Management with Pollution Control, Midwest Plan Service, Ames, Iowa, 1975.

stroke, and endless belt conveyors, and small and large tractors are examples of some of the mechanical equipment which is used.

Methods of collection and conveyance should be designed to prevent contamination of surface runoff below the feedlot. It is generally cost effective and environmentally sound to revise surface drainage around a feedlot and waste handling system to insure that storm water runoff from offsite areas do not reach the feedlot.

Waste Storage

Most animal waste systems accumulate manure in some form. The method of storage should accommodate the type of manure to be stored. Solid manure storage should be located for year-round access so that manure can be spread when field and weather conditions permit. Animal wastes should not be applied to farmlands under adverse soil or weather conditions, but must be stored until it can be incorporated into the soil. Surface runoff should be prevented from entering the storage facilities. Liquid manures may be stored in above or below ground storage tanks, or in holding ponds. A holding pond should be able to store liquid manure, washwater, and runoff for a designated period — generally 90 to 180 days.

To avoid groundwater pollution during storage, storage facilities should not be located on creviced bedrock or below the water table. The storage lagoon should be at least 100 feet from the nearest water supply. Solid manure storages should be at least 100 feet from the milkhouse or milking parlor to protect milk from absorbing odors from manure and to provide a sanitary condition in the milk handling areas.

Storing wastes alters the nutrient content of the manure. Dry storage systems usually require more labor to operate, but retain more nitrogen than liquid or slurry storage systems. Solid manure storage, referred to as stacking, is more common in stanchion dairy facilities than in any other livestock facilities because the amount of bedding used soaks up urine.[6]

Manure stored in liquid form is usually pumped to subsequent treatment or land utilization which makes the system advantageous where land for treatment or land utilization system is near the feedlot. Slurry wastes usually are transported by tank wagons to land application. Solid manures usually are applied to land using box type spreaders.

Waste Treatment

Waste treatment processes are used to modify the physical and chemical characteristics of the waste to reduce its pollution potential. They are usually applied to wastes in liquid form. The biological treatment methods for handling liquids can be classified as either anaerobic or aerobic. Anaerobic systems contain bacteria that can live in the absence of dissolved or free oxygen, whereas aerobic systems contain bacteria that require dissolved or free oxygen.

The anaerobic process can decompose more organic matter per unit volume than an aerobic one (see Table 20). The advantages of an anaerobic lagoon are:

1. In addition to labor savings in removing liquid manure from buildings, labor is saved by using irrigation equipment and techniques to dispose of liquids.

2. Long storage times permit labor flexibility while bacteria break down solids.

3. High degree of stabilization is achieved and may reduce odor during spreading.

4. Oxygen is not required and, therefore, no aeration system is needed, and the attendant construction and operating costs of aeration systems are avoided.

5. Nitrogen reduction is achieved, which is an advantage if disposal must be on small areas.

These systems also have disadvantages. They are:

1. Odors are produced if environmental or management changes reduce biological activity, or if lagoons turn over in spring and fall (bottom water rises and top water drops which causes odors from material on the bottom to be released to the surface).

2. Anaerobic lagoons function best during the summer and in areas without cold winters.

3. Fertilizer value is reduced (as much as 50 percent of the nitrogen is lost, and phosphorus and potash precipitate to the bottom of the lagoon).

An aerobic treatment system uses biological oxidation to convert organic matter to carbon dioxide, water, and microbe cells. The major advantages of aerobic treatment systems are:

1. Relatively odor-free operation.

2. Fast rate of biological growth.

3. Rapid adjustment to changes in loading and temperature.

4. Elevated temperatures are not required.

The major disadvantages are:

1. Oxygen is required.

2. High production of biological sludge increases the sludge disposal problem.

[6] *Livestock Waste Management with Pollution Control*, *Midwest Plan Service, Ames, Iowa, 1975.*

3. Relatively high space, maintenance, management, and energy requirements are necessary for artificial oxygenation.

4. Shallow depth required for systems without mechanical aerators results in a large surface area.

5. Fertilizer value is significantly reduced (as much as 80 percent of nitrogen is lost).

As much as 90 percent of the degradable organics of waste can be stabilized in an anaerobic treatment, while only about 50 percent is stabilized in aerobic systems. An anaerobic lagoon decreases biochemical oxygen demand (BOD) by 70 to 90 percent, reduces settleable solids in the supernatant by nearly 100 percent, removes 60 to 70 percent of total solids from the supernatant, does not effect pH, and increases nitrate nitrogen drastically. When an aerobic lagoon follows an anaerobic lagoon in series flow, the anaerobic lagoon may be assumed to remove 50 percent of the influent BOD for purposes of designing the aerobic lagoon.

The waste treatment systems reduce the raw waste loading significantly, but discharge levels for BOD_5 and solids can remain quite high (over 50 mg/l). The major use of the systems in southeastern Wisconsin should not be in treatment for discharge, but rather pretreatment for land application where land availability or suitability limit the amount of raw waste that can be applied without inducing surface runoff or groundwater pollution problems.

Storm Water Management

Many confined animal feeding facilities have a system for collecting and disposing of storm runoff. Retention basins are used to store runoff until disposal. Two methods are generally used to dispose of retained waters: pumping, hauling, and spreading; and irrigation. Runoff composition should be known prior to application. General practices to minimize pollution are to:

1. Use recommended irrigation management practices.[7]

2. Ensure that enough land is available for disposing of runoff applications. The amount of land required depends on whether the primary objective is to use the land as a disposal site (applying the maximum permissible amount without causing surface runoff or groundwater pollution) or for growing crops (applying the amount of effluent to provide enough water for optimum crop growth).

3. Ensure prompt incorporation of the wastewater into the soil, avoiding areas which will not readily absorb waste.

4. Apply erosion control practices described in Chapter 3.

In livestock facilities in the Region, all surface runoff should be diverted away from the feedlot site to avoid transport of feedlot wastes with the storm water to surface waters. The size of the retention basin would then be a function of precipitation volume on the feedlot only.

Ultimate Disposal

Because no practical way is available to adequately treat animal wastes from small facilities for discharge into streams, wastes usually are applied to agricultural land. Solid wastes are also applied to agricultural land as a means of disposal. If animal wastes are properly applied to land, the practice is beneficial to the land in providing nutrients for growing crops and in providing organic matter for improving physical soil properties to reduce erodability. Animal wastes applied to agricultural lands may be treated or untreated wastes from confinement areas or excretion from animals grazing on pastures.

If land is readily available and transportation is not a problem, raw wastes can be applied to land. The loading rate should be based on characteristics of the waste, kind of soil, climatic conditions, plant species, and depth to water table. Application of excessive amounts of waste can create problems. Weed seeds, salt content, and toxic substances may become limiting factors under some conditions.

Surface application of waste can be followed by no incorporation into the soil, immediate incorporation, or incorporation at a later date prior to planting a crop. Incorporation (usually by disking) as soon as possible after spreading reduces the pollution potential. This technique reduces the possibility of pollution from runoff and prevents loss of nitrogen compounds through volatilization. Adverse weather and soil conditions, crop stage, and the inability to commit labor and machinery to this job are possible constraints.

In some instances, solid waste materials from dairy operations and some beef cattle and swine operations become combined with quantities of liquids sufficient to produce a slurry (4 to 15 percent solids). Slurry wastes are applied to land by surface and sprinkler irrigation and tank spreaders, or by injection. Injection offers the least potential for surface water pollution.

Rates and methods of animal waste application on agricultural land are so diverse that they preclude specific recommendations. However, certain general procedures and practices can help to reduce pollution. They are:

1. Estimate the plant nutrient value of the waste, and apply it on land uniformly in accordance with crop requirements. (The nitrogen requirement of the crop is often a convenient basis for determining the amount of waste to be applied.) Typical plant nutrient values are shown in Table 21. Storage and treatment alter the amount of nutrients available.

[7] *National Engineering Handbook, Section 15, U. S. Soil Conservation Service, Washington, D. C., 1967.*

Table 21

COMPOSITION OF SOLID AND LIQUID MANURE MIXED WITH LIVESTOCK BEDDING OR LITTER

Solid Manure					
Manure Type	Percent Dry Matter	Nutrients in Pounds Per Ton of Raw Waste			
		Available N	Total N	P_2O_5	K_2O
Dairy	21	5	9	4	10
Beef	50	7	21	14	23
Swine	18	5	8	7	7
Poultry	75	36	56	45	34
Sheep	28	2	14	9	25

Liquid Manure (Lagoon Contents)					
Manure Type	Percent Dry Matter	Nutrients in Pounds Per Ton of Raw Waste			
		Available N	Total N	P_2O_5	K_2O
Dairy	1	2.4	4	4	5
Beef	1	2	4	9	5
Swine	1	3.2	4	2	4
Poultry	13	64	80	36	96

Source: Livestock Waste Facilities Handbook, Cooperative Extension Service, Iowa State University, Ames, Iowa, 1975.

2. Schedule the time and frequency of manure applications for maximum nutrient utilization by plants. Applications on row crops should be made prior to spring planting. Waste applications can be made on cool season grasses such as orchard grass during the summer. Waste applications on alfalfa can be made in the spring and after each cutting. Application on frozen ground should be totally avoided because of the inability of the frozen soil to incorporate the material and the risk of surface water pollution from runoff.

3. Incorporate manure into the soil as quickly as feasible following application, or inject the liquid wastes into the soil.

4. Ensure that enough land is available at the appropriate time for disposal of manure. For example, to maximize the utilization of raw waste, approximately 2.4 acres of land will be required for every 3 to 6 dairy cows, 5 to 10 beef animals, 20 to 40 hogs, and 400 to 800 laying hens.

5. When large amounts of waste are applied to the land, plant a highly productive row or forage crop (i.e., corn, soybeans, grass, or legume mixtures) to utilize the nutrients, reduce runoff, and reduce the amounts of nitrate and other pollutants that may reach the groundwater.

6. Avoid disposal on wet, steep, frozen, or snow-covered land; grass waterways generally should not be treated with wastes since the material will not be readily absorbed and may result in polluted runoff.

7. Apply soil erosion and runoff control practices (see Chapter 3).

<u>Energy Recovery</u>

The organic matter contained in wastes can serve as a source of energy for farm operations. Most facilities in the Region are not large enough to use available systems economically. Trends toward larger herds and potential joint handling of wastes may make the systems viable in the future.

A number of different processes can be used for recovering synthetic fuel from animal manure. These processes are in various stages of development but can be grouped into two categories: biological and thermalchemical. One frequently discussed biological process is the production of methane by anaerobic fermentation. A schematic of a conceptual single-phase methane generation system is shown in Figure 11.

A manure slurry containing 4 to 10 percent solids is fed into the digester. The loading range is usually based on the volatile solids or organic matter content of the manure. Loading ranges which have been used successfully for hog, dairy, and beef cattle vary from 0.1 to 0.3 pounds of volatile solids per cubic foot per day at 95° F. Retention times vary from 10 to 30 days.

The methane produced varies in quantity and quality. Table 22 shows methane production under the previously described conditions.

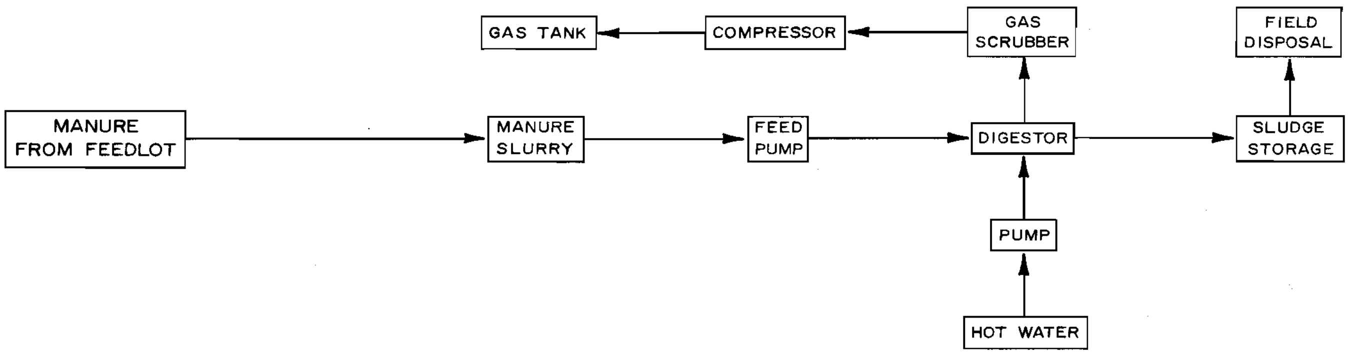
The gas produced contains other impurities such as SO_2 and small quantities of H_2S and H_2O. Methane content varies from 55 to 80 percent and CO_2 content from 20 to 45 percent. The methane must be purified to remove these contaminants.

During the operation of the digestor system, water and nondigestible and undigested matter are removed at a rate equal to the input rate. As much as 50 percent or more volatile solids reduction may be achieved by the digestion process. The effluent removed from the digestor may be recycled or disposed of on the land. The nutrient value of the wastes is reduced by the process.

At present, the cost of such a system precludes using it for the small size of animal systems encountered in the study area. One study shows the economic break-even point is a little less than 10 tons per day plant capacity at $2.00 per million Btu; while at $0.80 per million Btu, the break-even point is about 30 tons per day. This would represent feedlot facilities handling wastes from 500 to 1,500 animals, larger than any known facilities in the Region.

Figure 11

SINGLE-PHASE ANAEROBIC DIGESTION FOR METHANE PRODUCTION



Source: William J. Jewell, Energy, Agriculture, and Waste Management, Ann Arbor Science Publication, Inc., Ann Arbor, Michigan, 1975.

Table 22

METHANE PRODUCTION RATES

Livestock (1,000 Pounds Live Body Weight)	Methane Production Range, cubic feet/day (at 95° F)	Methane, (percent)
Dairy	42 - 60	60 - 80
Beef	30 - 36	60 - 80
Hog	29 - 100	55 - 75

Source: William J. Jewell, Energy, Agriculture, and Waste Management, Ann Arbor Science Publication, Inc., Ann Arbor, Michigan, 1975.

Pastureland Management

Pastures can be a major component of livestock production although the practice is not common in the Region. Cow-calf enterprises, dairy farms, and some hog operations use pasture. Grazing animals deposit manure directly on the land. Although a relatively large land area may be available to grazing animals, they tend to concentrate around feeding, watering, and resting areas. Wastes can also become concentrated in these areas. The following are practices that minimize pasture contributions to water pollution:

1. Maintain an adequate land-to-livestock ratio. Avoid concentrations of animals that will create holding areas rather than grazing areas.

2. Maintain a highly productive forage on the land to retard runoff, entrap animal wastes, and utilize nutrients.

3. Plan a stocking density and rotation system of grazing to prevent overgrazing and eroding of the soil.

4. Locate feeders and waterers a reasonable distance from streams and water courses. Move them to new locations often enough to avoid creating erodible paths through repeated trampling by livestock.

5. Provide an adequate land adsorption area downslope from feeding and watering sites, preferably with a filter strip of lush forage growth between such sites and the streams.

6. Provide limited access to streams and ponds. Use fencing to keep livestock from entering critical stream reaches.

7. Provide fences to prevent animals from wading in stream at points where they may concentrate for drinking. Fencing may be impractical, however, for many pasture operations.

8. Pump water from a stream, farm pond, or well to watering troughs or tanks where the number of animals or the characteristics of land present critical pollution problems.

9. Provide summer shade, using trees or artificial shelters to lessen the need for the animals to enter the water for relief from the heat. The same precaution used in locating feeders and waterers should be followed for locating shelters.

COST OF ANIMAL WASTE CONTROLS

Most of the figures cited in the literature are not relative to the study area because they deal with a much larger size of operation. A simple way to accurately predict the construction costs and operation and maintenance costs of a facility does not exist. Table 23 contains cost data for handling of animal waste in terms of dollars per animal based on information provided in references.[8]

[8] *Agricultural Engineering Department, "Considerations in Selecting Dairy Manure Handling Systems," AEN-7, University of Wisconsin-Madison, November 1975.*

Table 23

COSTS OF ANIMAL WASTE HANDLING
AT 50 TO 100 ANIMALS PER FEEDLOT

Waste Handling Operations	Capital Cost[a] (per cow) (in Dollars)	Annual Operating Cost[a] (per cow) (in Dollars)
Barnyard and Feedlot Cleaning	60.00	4.50
Storage:		
Dry Stacking	110.00	5.60
Liquid and Slurry Tank	300.00	4.00
Liquid and Slurry Basin	190.00	4.80
Hauling and Spreading		
Dry	20.00	17.00
Liquid—Slurry-Tank Truck	64.00	21.70
Liquid—Irrigation	96.00	14.00

[a]Base year not presented, assume 1975 dollars.

Source: Adapted from Agricultural Engineering Department, "Considerations in Selecting Dairy Manure Handling Systems," AEN-7, University of Wisconsin-Madison, November 1975.

Costs at a specific site can be expected to vary widely, but the values presented should be adequate for regional analysis of control alternatives.

Values for anaerobic and aerobic lagoon treatment systems are quite variable[9] with average cost of $.30 per cubic yard of volume. One report[10] provides annual cost per animal values of $12 for construction and $3/year/animal operating costs (values updated to August, 1976).

Order of magnitude costs for a treatment system consisting of a debris basin, a retention basin capable of handling runoff from a 10 year-24 hour storm from a feedlot with storm water diverted around the lot, followed by tank truck application to agricultural fields have also been developed, as follows:

Feedlot Capacity	Annual Capital Cost[a]/Head (in Dollars)	Annual Operating Cost/Head (in Dollars)
25- 125 Head	27	2.40
126- 500 Head	20	1.80
501-2,100 Head	13	1.30

[a]August 1976 values. Capital cost amortized over 10 years at 7 percent.

The factors indicate the economy of scale associated with larger lots.

Proper application of animal wastes on agricultural land can minimize potential pollutant transfer to surface and groundwaters of the region. Storage facilities will be required to ensure proper timing of application.

[9] *U. S. Environmental Protection Agency, "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Feedlots Point Source Category," EPA 440/1-75-004-9, January 1974.*

[10] *Ibid.*

(This page intentionally left blank)

Chapter VI

CONSTRAINTS TO IMPLEMENTATION OF CONTROLS

This report has presented information on alternative control systems to control agricultural runoff pollution loads. In general, methods of controlling all agricultural runoff are known and their effectiveness documented. However, the controls are only effective if applied. Controls can be implemented on a voluntary basis or through regulatory measures. Both of these means of implementation have certain constraints. The constraints to voluntary implementation are:

1. Human nature.
2. Economics.
3. Lack of information and education.
4. Lack of incentives for implementation of known controls.

Constraints to regulatory implementation are:

1. The time required to pass legislation.
2. Failure of lawmakers sometimes to have a full understanding of the problem.
3. The administrative difficulty of enforcing pollution prevention and control measures which are integral to many operations of the agricultural land owner.
4. Difficulty, under the present state of the art, of linking land use and land management practices to water quality conditions resulting from those practices or changes to those practices making standards of performance difficult to develop.

While voluntary implementation may be the most desirable method, it may not always be the most feasible or reliable. The human element makes voluntary implementation unpredictable. Historically, Soil and Water Conservation Districts, the Soil Conservation Service, the Cooperative Extensive Service, and the Agricultural and Stabilization and Conservation Service, the Wisconsin Department of Natural Resources, and the Southeastern Wisconsin Regional Planning Commission have promoted practices which foster wise land use as well as produce pollution control benefits. While programs of some of these agencies have been in effect for about 40 years, they have met with limited success. In many instances, the conscientious farmer applies practices because he recognizes the need before it becomes a problem. However, in many other instances, the need must develop into a critical problem before it is recognized. For example, when a gully becomes so deep that it cannot be crossed with a tractor, a farmer may request assistance.

In some instances, the human element and economic elements can be interrelated. If the choice must be made between purchasing a new car and installing a terrace system, pressures from other family members may play an important role in the selection.

If only a certain number of dollars from the farmer's income are available for return to the farming operations, needed building repairs, or equipment replacement may take precedence over istallation of pollution control practices. If a tractor requires replacement, on the short-term basis, this may be a more critical item than the construction of an animal waste facility, and may provide a far more attractive immediate return on investment.

Information and education programs provided by the Cooperative Extension Service, producers, and manufacturers cannot be expected to reach all the public nor can these programs be expected to be received by all who are exposed to them. Traditions are difficult to change and the management capabilities of individuals can differ greatly.

Although regulatory controls may be the least desirable, they can be the most effective. Like voluntary controls, regulatory controls have certain constraints. The legislative process can be a slow one. In many situations, the enactment of much needed legislation can take three to four years. During this time, costly and irreversible problems can be created.

Lawmakers do not always have a full understanding of the situation and are not always able to anticipate all the problems a particular piece of legislation may produce. To be effective, laws must be enacted at the proper level—local, state, or federal. Laws should be drafted so as not to place an undue burden on only one part of society.

Regulations are only effective if they are enforced. In some instances, finding an entity with the resources and authority to enforce a particular regulation is difficult. Being able to substantiate claims of water pollution from a particular farming enterprise in a court of law may be even more difficult.

The major difficulty of controlling agricultural nonpoint sources of water pollution will not be a lack of effective control methods, but a lack of effective methods to have known controls applied. Applying known controls will improve water quality, but the extent of improvement obtained by adopting a control is difficult to predict.

(This page intentionally left blank)

APPENDICES

(This page intentionally left blank)

Appendix A

SELECTED REFERENCES

Southeastern Wisconsin Regional Planning Commission, A Regional Land Use Plan and a Regional Transportation Plan for Southeastern Wisconsin—2000, Planning Report No. 25, Volume 1, April 1975.

Kluesner, J.W., "Nutrient Transport and Transformations in Lake Wingra, Wisconsin," Ph.D. thesis, Water Chemistry Department, University of Wisconsin, Madison, Wisconsin, 1972.

Hoeft, R. G., D. R. Keeney, and L. M. Walski, "Nitrogen and Sulfur in Precipitation and Sulfur Dioxide in the Atmosphere in Wisconsin, Journal of Environmental Quality, Volume 1, No. 2, 1972.

Chapin, J. D. and P. E. Uttormark, "Atmospheric Contributions of Nitrogen and Phosphorus," University of Wisconsin Water Resources Center, Madison, Wisconsin, February 1973.

Murphy, T. J. and P. V. Doskey, "Inputs of Phosphorus from Precipitation to Lake Michigan," prepared for U. S. Environmental Protection Agency, EPA 600/3-75-005, December 1975.

Nonpoint and Intermittent Point Source Controls—Development of Structural Control Techniques and Cost Information, prepared by Stanley Consultants for the Miami Conservancy District, January 1976.

Nonpoint Pollution Evaluation—Atlanta Urban Area, prepared by Black Crow and Ediness for Savannah District Corps of Engineers, 1975.

Guidelines for Air Quality Maintenance Planning and Analysis, Volume 3, Control Strategies, U. S. Environmental Protection Agency, July 1974.

U. S. Environmental Protection Agency, Methods for Identifying and Evaluating the Nature and Extent of Non-Point Sources of Pollutants, EPA 430/9-73-014, U. S. Government Printing Office, October 1973.

Willrich, T. L., et al, "Agricultural Practices and Water Quality" in Proceeding of a Conference Concerning the Role of Agriculture in Clean Water, November 1969, Iowa State University, Ames, Iowa, November 1970.

Graf, Walter Hans, Hydraulics of Sediment Transport, McGraw-Hill, New York, New York, 1971.

McElroy, A. D., et al, "Loading Functions for Assessment of Water Pollution from Nonpoint Sources," EPA/2-76-151, May 1976.

U. S. Environmental Protection Agency, "State-of-the-Art: Sand and Gravel Industry," EPA-660/2-74-066, June 1974.

Harms, L. L., J. N. Dornbush, and J. R. Andersen, Physical and Chemical Quality of Agricultural Land Runoff, U. S. Environmental Protection Agency, Project No. R-800400, 1973.

Loehr, R. A., "Characteristics and Comparative Magnitude of Nonpoint Sources," Journal of Water Pollution Control Federation, Volume 46, No. 8, August 1974.

Lin, S., "Nonpoint Rural Sources of Water Pollution," Circular III, Illinois State Water Survey, 1972.

Stoltenberg, G.A., "Water Quality in an Agricultural Watershed," paper presented at Twentieth Annual Conference on Sanitary Engineering, University of Kansas, Lawrence, Kansas, January 1970.

Berkowitz, et al, "White Clay Lake Watershed Water and Related Land Resources Management Study," University of Wisconsin-Madison, Unpublished, December 1975.

Mulch Tillage in Modern Farming, Leaflet 554, U. S. Department of Agriculture, Washington, D. C., 1971.

"No Nonsense Guide to No-Till Farming," Allis-Chalmers, Farm Equipment Division, Milwaukee, Wisconsin.

Stewart, B. A. et al, Control of Water Pollution from Cropland, Volume 1, A Manual for Guideline Development, Office of Research and Development, Environmental Protection Agency, EPA 600/2-75-026a, February 1975.

U. S. Soil Conservation Service Technical Guide for Illinois, U. S. Department of Agriculture, September 1970.

Engineering Field Manual for Conservation Practices, U. S. Soil Conservation Service, 1969.

Methods for Controlling Water Pollution from Agricultural Nonpoint Sources, U. S. Environmental Protection Agency, EPA 430/9-73-015, October 1973.

Methods for Identifying and Evaluating the Nature and Extent of Nonpoint Sources of Pollutants, U. S. Environmental Protection Agency, EPA 430/9-73-014, October 1973.

U. S. Environmental Protection Agency, Processes, Procedures, and Methods to Control Pollution Resulting from Silvicultural Activities, EPA 430/9-73-010, U. S. Government Printing Office, October 1973.

Wischmeir, W. H. and D. D. Smith, Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains, Agricultural Handbook No. 282, Agricultural Research Service, U. S. Department of Agriculture, May 1965.

Allen County Soil and Water Conservation District, Environmental Impact of Land Use on Water Quality, Operations Manual for the Black Creek Study, Maumee River Basin, Allen County, Indiana, NTIS PB 235 526, March 1974.

Spier, C. D., Types and Uses of Nitrogen Fertilizer for Crop Production, Agronomy Guide, Cooperative Extension Service, Purdue University, West Lafayette, Indiana, 1974.

U. S. Environmental Protection Agency, "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Feedlots Point Source Category," EPA 440/1-75-004-9, January 1974.

Miner, J. Ronald, "Agricultural Waste Management," Journal of the Environmental Engineering Division, Volume 100, American Society of Civil Engineers, April 1974.

Livestock Waste Management with Pollution Control, Midwest Plan Service, Ames, Iowa, 1975.

Livestock Waste Facilities Handbook, Cooperative Extension Service, Iowa State University, Ames, Iowa, 1975.

National Engineering Handbook, Section 15, U. S. Soil Conservation Service, Washington, D. C., 1967.

Jewell, William J., Energy, Agriculture, and Waste Management, Ann Arbor Science Publication, Inc., Ann Arbor, Michigan, 1975.

Bruns, E. G. and J. W. Crowley, "Solid Manure Handling for Livestock Housing, Feeding and Yard Facilities in Wisconsin," University of Wisconsin Extension, November 1972.

Jones, P. H., "Theory and Future Outlook of Animal Waste Treatment," in Proceedings Animal Waste Management, Cornell University, January 1969.

Agricultural Engineering Department, "Considerations in Selecting Dairy Manure Handling Systems," AEN-7, University of Wisconsin-Madison, November 1975.

Stanley Consultants for the Omaha-Council Bluffs Metropolitan Area Planning Agency, Agricultural Wastes, Technical Report 107-1 of the Comprehensive Water Pollution Control Plan, September 1972.

Appendix B

LIST OF ABBREVIATIONS

Abbreviation	Stands For
COD	Chemical Oxygen Demand
BOD_5	Five-Day Biochemical Oxygen Demand
TSS	Total Suspended Solids
TN	Total Nitrogen
NH_3-N	Ammonia Nitrogen
NO_3-N	Nitrate Nitrogen
TP	Total Phosphorus
OP	Orthophosphate Phosphorus